Designing the Tradeoff between Consumer Expectations of Water Quality and Reduction in Energy Use for Water Utilities in Japan(Dissertation_全文)

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Designing the Tradeoff between Consumer Expectations of Water Quality and Reduction in Energy Use for Water Utilities in Japan

by

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in
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ABSTRACT

This study was performed to develop a methodology for water utilities in Japan to make tradeoffs between meeting consumer expectations with respect to water quality and reducing energy use. With significant degradation in raw water quality as a result of climate change, and given that advanced water treatments are typically more energy intensive, utilities will be forced to make a choice between meeting the consumer expectations for water quality and curtailing energy use in a bid to mitigate the impacts of climate change. Because it is difficult to achieve both targets, the challenge for utilities, thus, is to arrive at an optimal tradeoff between the water quality and energy consumption.

The first objective of the study was to develop a Performance Indicator (PI) system, which can be used to evaluate models under different scenarios of climate change. This is important because the current PI system has 137 items, which are too many in number to be incorporated as evaluation parameters. The study used Principal Component Analysis, a statistical technique, to reduce the number of indicators to a more manageable set. In doing so, a new PI system called 9-component Performance Indicator System (9-cPIS) was developed. The components of the 9-cPIS have been called — Economic Value of Water, Employee Productivity, Financial Sustainability, Adaptive Management, Private Investment, Green Water Supply, Consumer Satisfaction for Water Quality, Emergency Response Index, and Earthquake Resistant Water Supply. The 9-cPIS contains only 33 items, which is not only useful for modeling studies but also useful for small water utilities in Japan, which do not have the resources to evaluate all the 137 originally recommended items. Apart from its use in modeling studies, the applications of the 9-cPIS in evaluating business models and implementing the PDCA cycle have also been illustrated.

The second objective of the study was to introduce a concept called "Public Interest (P_{INT})" in the PI system. P_{INT} identifies those areas of the supply system in which the public has interest, thereby providing an insight into consumer' expectations. The P_{INT} was estimated by conducting a questionnaire survey in the Kansai region of Japan, and it was quantified by using Factor Analysis. Eight variables were used in the questionnaire survey to estimate the P_{INT} – Trust in water utility, Good quality water, R&D in water utility, equity of distribution, price of water, employee productivity in water utility, financial state of water utility, customer service. Of these, the first five variables formed the P_{INT} factor, meaning the consumers are interested in these variables only. The next two variables in the list, along with R&D, made up the Public Disinterest factor – items that do not arouse public interest. Further, relationships were derived between P_{INT} and each component of the 9-cPIS to understand the strength of association between the two. Only the Consumer Satisfaction of Water Quality showed a strong positive relationship with the P_{INT}, suggesting that good tap water quality is the most important PI from the consumers' point of view. A multiple regression equation between the $\mathbf{P_{INT}}$ and all components of the 9-cPIS together was also

developed to help in evaluating tradeoffs between the consumer expectations and reductions in GHG emissions.

The third objective of the study was to develop numerical models between certain variables for a selected water utility – Kobe City Waterworks – and evaluate the models under various conditions of climate change, in order to design the tradeoff between meeting consumer expectations of water quality and reduction in energy use. Two conditions of climate change were considered – Increase in raw water turbidity and Decrease in GHG emissions. Based on these six models were developed: Raw water turbidity – Power consumption model, GHG emissions – Water production volume model, Power consumption – Water production volume model, Water production volume – Financial Sustainability model, Water production volume – Economic Value of Water model, and Water production volume – Green Water Supply model. Using numerical modeling, via Monte Carlo simulations, the models were evaluated for 5, 10, 15, 20 and 25% reduction in GHG emissions from 2010 levels, and 5, 10, 15, 20, 50, 100, 150%, and max (100 Degrees) increase in turbidity from 2010 values. Further, selected components of the 9-cPIS and the P_{INT} were also evaluated under the same scenarios to see how the system will behave in context of climate change. The tradeoff analysis suggested that the optimal reduction in GHG emissions was in the range 10.5 – 14.5% for the various scenarios of increase in raw water turbidity. The study also investigated practical scenarios for the Kobe City Waterworks for the years 2015, 2020 and 2025. After establishing a minimum per capita water demand, and following the population growth trend, the target power consumption for established for each year, under the various conditions of climate change. The results suggest for all the three years, only up to 15% reduction in GHG emissions, under up to 50% increase in raw water turbidity, is possible by only reducing the production volume. Any further reduction in production volume will result in per capita water consumption below the established minimum value, which is not acceptable. To achieve higher GHG emission reduction targets (20 and 25%), while providing the minimum per capita demand, the Kobe City Waterworks will need to consider the usage of renewable energy (solar or wind).

The study has both theoretical and practical implications. On the theoretical front, the concept of Public Interest in PI systems has been introduced, which can be further refined to address other pertinent issues of water management. On a practical front, first, the 9-cPIS has been developed. This simple indicator system evaluates most of the current and future concerns for Japanese water utilities, and is much easier to manage because of its condensed nature – 33 items as opposed to 137 items recommended by the JWWA. Second, a general methodology has been developed to estimate the tradeoff between meeting consumer expectations of water quality and reduction in energy use. Further, actual tangible solutions, with data, have been provided to help the Kobe Waterworks utility to meet the GHG emission targets under various scenarios of climate change.

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ABBREVIATIONS USED FREQUENTLY IN THE STUDY

9-cPIS	9-component Performance Indicator System
AARE	Average Absolute Relative Error
AM	Adaptive Management
CSWQ	Consumer Satisfaction for Water Quality
EP	Employee Productivity
ERI	Emergency Response Index
ERS	Earthquake Resistant Supply
EV	Economic Value of Water
FA	Factor Analysis
FS	Financial Sustainability
GAC	Granulated Activated Carbon
GHG	Green House Gases
GWS	Green Water Supply
IBNET	International Benchmarking Network for Water and Sanitation Utilities
IPCC	Intergovernmental Panel on Climate Change
IWA	International Water Association
JWRC	Japan Water Research Center
JWWA	Japan Water Works Association
KMO	Kaiser Meyer Olkin
MLITT	Ministry of Land, Infrastructure, Transport and Tourism
MLR	Multiple Linear Regression
P_{DIN}	Public Disinterest
P_{INT}	Public Interest
PCA	Principal Component Analysis
PDCA	Plan Do Check Act
PIs	Performance Indicators
PIN	Private Investment
RMSE	Root Mean Square Error
RSF	Rapid Sand Filtration
THM	Trihalomethanes
TOC	Total Organic Carbon
TON	Threshold Odor Number
UNFCC	United Nations Framework on Climate Change
UV	Ultra Violet

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CHAPTER I

INTRODUCTION

1.1 General

Water is increasingly becoming a stressed natural resource. Exploding population, indiscriminate withdrawal, and wasteful attitudes have all been factors for the state of water that it is in today. Additionally, climate change effects on water resources further compound the problem. As management and control of water resources has grown as a political and economic force in most parts of the world, understanding the potential impacts of current and future climate conditions on hydrologic processes and water supplies has become even more critical. The Fourth Assessment Report, "Climate Change 2007", of The Inter Governmental Panel on Climate Change (IPCC, 2007) has eliminated many aspersions that previously shrouded both scientific and policy discussions about climate change. There is an increasing consensus among the scientific community that climate change will surely have an adverse effect on water resources (Cromwell et al., 2010; Bates et al., 2008; Xu et al., 2007 etc.). Arnel and Delaney (2006) have very aptly summarized the potential impacts of climate change on water supply systems as follows

- It may alter the reliability of raw water sources by changing the magnitude and frequency of flows
- It may alter the reliability of supply infrastructure, e.g. dams, reservoirs
- It may alter the raw water quality and thereby the ability to treat raw water to potable standards
- It may alter the demand of water, and the ability to meet these demands, particularly at times of peak demand.

In light of the aforementioned, the challenge of providing safe and reliable water supply to consumers becomes even more pronounced for water utilities worldwide. At a water utility level, while a number of studies have focused on suggesting remedial measures for addressing the water quantity aspect in response to climate change (e.g. Bakker and van Schaik, 2010; Smith, 2010; van der Berg et al., 2010 etc.), very few studies have been conducted on dealing with change in water quality. There is a dire need for doing so, especially in developed countries, where the consumers' expectations of the water quality is very high. The type of finished water quality depends upon the type of treatment applied, and more advanced treatments are typically more energy intensive. Thus, by adopting advanced levels of water treatment in order to meet consumer expectations, the utilities will indirectly contribute to the phenomenon of climate change, thereby exacerbating the already disconsolate situation.

With significant degradation expected in raw water quality, as a result of climate change, there is a strong possibility that utilities may have to change or modify the treatment technology, to ensure consumer satisfaction. In all likelihood this will involve more use of energy, thus forcing the utilities to make a choice between meeting the consumer expectations with respect to water quality and curtailing energy use in a bid to mitigate the impacts of climate change. Given that it will be difficult to achieve both targets, the challenge for utilities, thus, is to arrive at an optimal tradeoff between the water quality and energy consumption.

1.2 Statement of the problem

1.2.1 Need for reduction in Green House Gases (GHG) emissions

The IPCC recognizes that climate change will exacerbate the current stress on water resources. Global warming causes climate change, which in turn is directly proportional to the amount of GHG in the atmosphere. Increased levels of GHG thus lead to a more rapid change in the climate regimes. Figure 1.1 shows the GHG emissions of the top ten countries in the year 2008.

As seen in Figure1.1, Japan ranks fifth among the individual countries that produce the maximum CO_2 emissions. Under the Kyoto Protocol that Japan ratified in June 2002, the GHG subject to the quantified reduction commitments are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro fluorocarbons (HFCs), per fluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

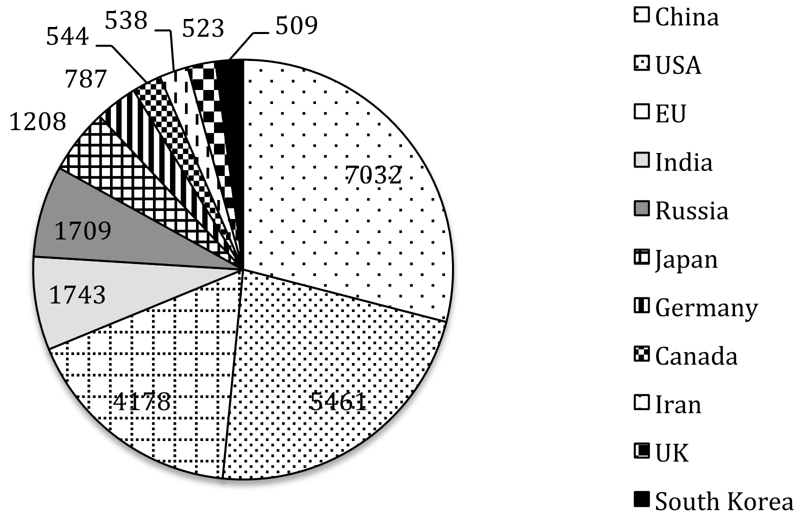


Figure 1.1: Top 10 countries by GHG emissions in 2008 (Million tons of CO_2) Source: United Nations Statistics Division

These quantified reduction commitments have been established for each country. During the first commitment period, from 2008 to 2012, Japan committed to reducing these greenhouse gases by 6% from the base year's emissions (1990 for CO_2, CH_4, and N_2O, while 1995 for HFCs, PFCs, and SF_6).

In order to monitor the GHG emission targets, and achievements, of each member country, The United Nations Framework on Climate Change (UNFCC) maintains a database of annual GHG emissions. Based on this UNFCC data, as seen in Figure 1.2, Japan's GHG emissions increased by almost 6% from the base year in 2005 representing a 12.2% gap from the target (UNFCC, 2012a).

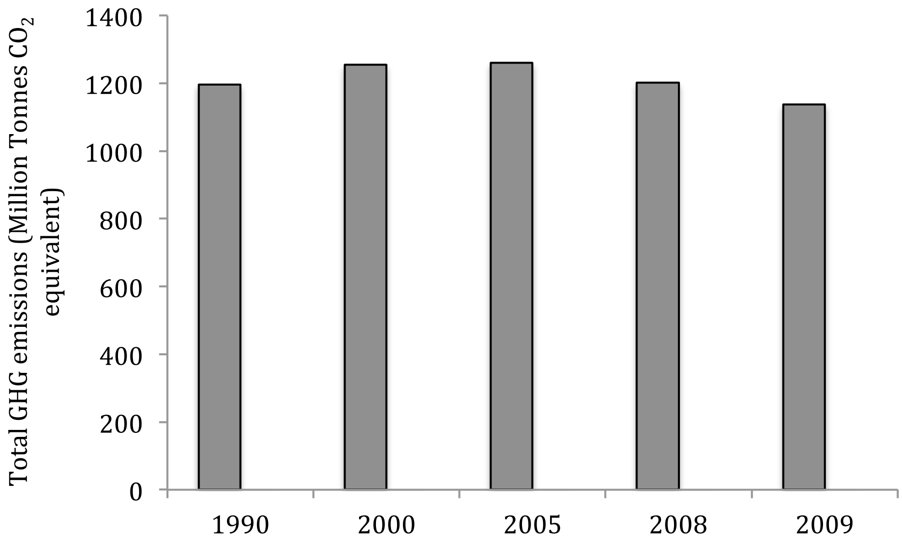


Figure 1.2: Trend for Japan's total GHG emissions in $C0_2$ equivalent (Source: UNFCC, 2012a)

However, significant reductions in GHG emissions were achieved in the years 2008 and 2009, and at the end of 2009 the reduction was at 5% from the base year. The government of Japan is committed to reduce GHG emissions by 25% by 2020 and 60-80% by 2050, compared to the base year of 1990. Such an initiative will require all sectors to contribute collectively to the GHG reduction vision. This endeavor becomes even more challenging in light of the recent nuclear disaster in Sendai since a major criteria for achieving the GHG reductions was based on increasing the nuclear energy output. Given the public outcry and protests from environmentalists, it may be difficult to meet the emission targets. Although the water sector in Japan is not a major contributor of GHG emissions (less than 1% of the total emissions), in light of the above, it is very important for the water sector in Japan to first, develop feasible strategies to adapt to the changes that will be brought about by climate change (adaptation), and second it is important for the sector to make contributions in whatever way possible to mitigate the impacts that climate change will bring (mitigation).

1.2.2 Water quality concerns

On the other hand, the consumer expectations of water quality in Japan have been rising over the years. The traditional forms of water treatment, which use significant residual chlorine is no longer acceptable to the consumers because of the unpleasant taste and odor. With progress in technology and ease in obtaining information, consumers are becoming more sensitive to the type and nature of treatment processes used by the utilities. They are, hence, more likely to reject the tap water which does not meet their expectations, especially since other easy options like bottled water are easily available. Figure 1.3 shows the annual trend of number of customer complaints about taste and odor for Osaka City in Japan.

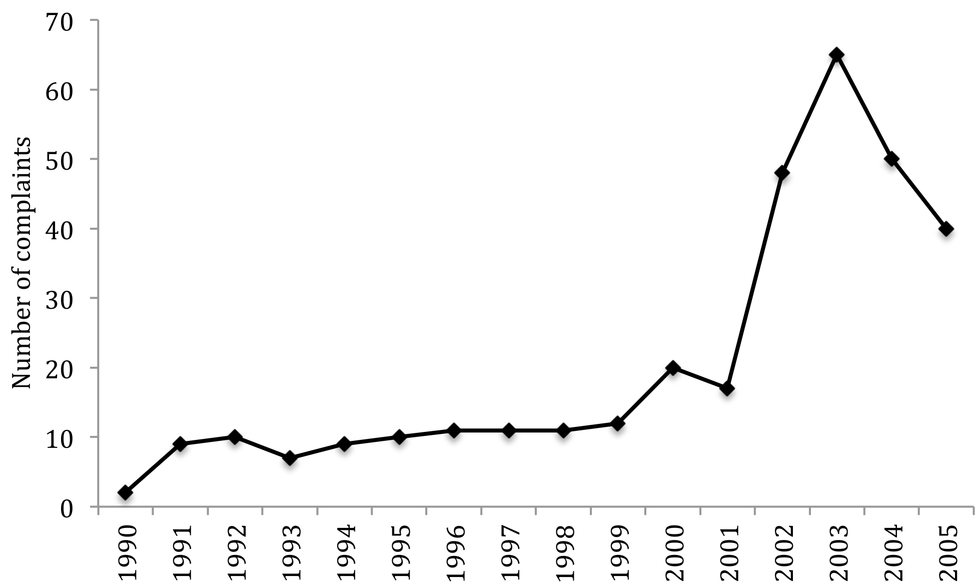


Figure 1.3: Customer complaints regarding taste and odor of drinking water in Osaka City (Source: Itoh et al. 2007)

The tap water quality provided by the Osaka Waterworks Bureau is among the best in Japan but in spite of that there have been a rising number of complaints regarding the taste and odor of water. Ironically, the number of complaints rose dramatically after the year 2000, when the Waterworks Bureau adopted advanced water treatment consisting of ozonation and Granular Activated Carbon (GAC), apart from the traditional set up.

To examine the consumer behavior with regards to water quality in Japan, Itoh et al. (2007) performed a survey in Osaka City. One of their findings revealed that less than 25% of the respondents directly consumed tap water, indicating a general dissatisfaction with the quality of tap water. By using casual models, and covariance structure analysis, they established that consumer behavior, and thereby satisfaction, was governed by three main constructs: Odor, taste and health concern. Hence, hard measures like ‘technological input’ or soft measures like ‘information availability’, which have the ability to reduce the taste, odor and health concerns have the potential to improve customer satisfaction.

In view of the rising number of water quality complaints, some recent studies have been conducted on meeting the consumer expectations. Ishimoto and Itoh have proposed a target Threshold Odor Number (TON) value of 4 for finished water, in order to reduce taste and odor concerns. This value was established based on three phases on consumer behavior when presented with an offensive water sample. The first phase is the ‘detection’ phase where consumers are just able to notice the unpleasant taste or odor. This is followed by the ‘emotion’ phase, where consumers start feeling uncomfortable with the taste or odor. The last stage is the ‘action’ stage when the consumers decide to reject the water because of its unpleasant odor and taste. The target TON of 4 lies within the ‘emotion’ phase. In another related study, Echigo et al. (2012), proposed a new treatment process for the Osaka Waterworks Bureau, to minimize the chlorinous odor. The new process excludes the GAC unit from the original treatment system and includes the use of Advanced Oxidation Process (AOP) coupled with Ultra Violet treatment, and an Ion Exchange unit.

Achieving a target TON of 4 is quite challenging in the existing situation, and is likely to be more difficult in future with expected degradation in raw water quality because of climate change. Not only are the advanced treatment technologies energy intensive, they are also significantly more expensive compared to the traditional forms of treatment. In such a situation, it is very unlikely that the utilities will be able to meet both the GHG emission targets as well as the consumer expectations for water quality. Hence, the pressing need of the hour is to design a method to arrive at an optimal tradeoff between the two.

1.3 Objectives and scope of the study

The overall objective of the study is to develop a methodology for water utilities in Japan to design the tradeoff between meeting consumer expectations with respect to water quality and reducing the energy use.

The sub objectives (thematic objectives) are highlighted as under

- Revise the existing Performance Indicator (PI) system for water supply utilities in Japan to test numerical models required for tradeoff between water quality and reduction in energy use

- Introduce the concept of ‘Public Interest’ in water supply to understand and quantify consumer expectations

- Using numerical modeling, to develop a methodology for tradeoff between consumer expectations of water quality and reduction in GHG emissions for a selected utility — Kobe City Waterworks, Japan.

Figure 1.4 shows the integrated research model that encompasses the three thematic objectives. Accordingly, the first objective culminates into the development of a new revised PI system called the "**9-component Performance Indicator system (9-cPIS)**", to evaluate the performance of the system for different scenarios of climate change.

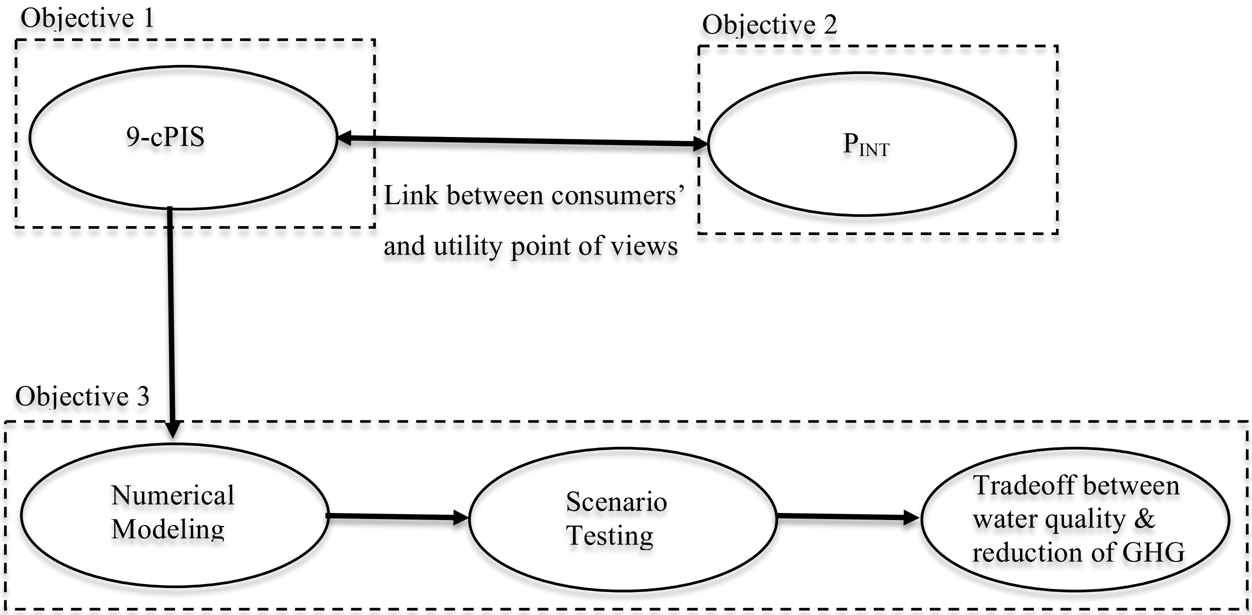


Figure 1.4: Integrated research model

The second objective evaluates the **"Public Interest P_{INT}"**, and identifies areas of the supply system in which the public are interested. This is a novel concept, introduced in this research, which tries to address the consumer's point of view by accounting for the consumer expectations, especially in context of water quality.

The third objective focuses on developing regression models for Kobe City Waterworks between the explanatory variables of the 9-cPIS and certain independent variables that are likely to be affected by climate change. The models have been evaluated, under different scenarios of change, and the performances have been studied by using selected components of the 9-cPIS. Based on the evaluation results, a methodology for tradeoff between consumer expectations of water quality and reduction in energy use has been developed.

1.4 Structure of thesis

The current chapter (Chapter 1) of this dissertation has provided a background and rationale for conducting the study. The statement of the problem has been introduced based on which the objectives and sub objectives (thematic objectives) of the study have been defined. An integrated research model explaining the flow and linkage of activities across the three sub objectives has been explained further.

In Chapter 2 of the dissertation, a Performance Indicator system (9-cPIS) has been developed considering the current and future concerns for water utilities in Japan. There is currently an existing PI system in place recommended by the Japan Waterworks Association (JWWA) but this system has far too many items (137), which are difficult to monitor for most water utilities. Further, it would be virtually impossible to test the regression models proposed in this study against all these indicators. Hence, Principal Component Analysis was used to reduce the dimensionality of the original set, while at the same time maintaining the maximum variance from the original set, resulting in the development of the 9-cPIS.

In Chapter 3, a concept 'Public Interest P_{INT}' has been introduced. While the 9-cPIS has been developed from the utility point of view, P_{INT} identifies the aspects of the supply system, which naturally interest the public. Having this knowledge will help in understanding the consumer expectations, which is crucial in deciding feasible options for GHG emissions reduction. The P_{INT} has been evaluated through a questionnaire survey, and then quantified by performing a confirmatory Factor Analysis. Regression equations have been further developed to relate the P_{INT} with the components of 9-cPIS.

Chapter 4 deals exclusively with developing regression models between the explanatory variables of selected components of the 9-cPIS and two key variables that are expected to be affected by climate change – Raw water turbidity and GHG emissions. The rationale for choosing these variables is that the utilities must be prepared to address changes in consumer expectations because of degrading raw water quality caused by climate change, while at the same time contribute to the nation's emission targets in the form of reducing GHG emissions. The models were developed for a selected water utility – Kobe City Waterworks, Japan.

Chapter 5 evaluates the models developed in Chapter 4 against different scenarios of climate change – increasing levels of raw water turbidity, and decreasing levels of GHG emissions. Using Monte Carlo simulations, the power consumption under different scenarios has been calculated from which the water supply volume has been estimated. The trend of selected components of the 9-cPIs under different scenarios has been developed, from which the P_{INT} has been evaluated for the various scenarios. Based on the results of the analysis, a methodology for tradeoff between the consumer expectations of water quality and reduction in energy use has been proposed.

Chapter 6, the last chapter, summarizes the scope and extent of the entire research work, and key findings of the study have been presented. Recommendations and suggestions for utilities in Japan, especially the Kobe City Waterworks, have been provided, and scope for further study has been defined.

CHAPTER II

DEVELOPING THE 9-COMPONENT PERFORMANCE INDICATOR SYSTEM (9-cPIS)

2.1 Introduction

2.1.1 Performance Indicators (PIs)

The reliable supply of safe and good tasting water is the primary objective of any water supply utility. To evaluate and monitor the rate of success, or failure, in meeting this objective, water supply utilities employ a set of Performance Indicators (PIs), which reflect on the various components of the water supply system. The ultimate goal of a PI is not just statistical evaluation but also to provide information for decision-making. Hence, the usefulness of PIs does not only pertain to water supply undertakings but also to regional/national planning bodies, regulatory agencies, funding bodies etc. (Algere 2002).

Various international organizations, such as the International Water Association (IWA) (Algere et al., 2006), World Bank (WB) (WB 1999), World Health Organization (WHO) (WHO 2000) and International Benchmarking Network for Water and Sanitation Utilities (IBNET 2005) etc. have proposed different terminologies of PIs but the main objectives are alike. The IWA, one of the leading research agencies in the water sector, recommends six themes of performance indicators, namely, water resources, personnel, physical, operational, quality of service and economic & financial indicators. Table 2.1 presents the summary of the main components of PIs as described by various organizations.

Table 2.1: Performance Indicator themes recommended by various international organizations

IWA (2006)	IBNET (2005)	WHO (2000)	WB (1999)
• Water Resources • Personnel • Physical • Operational • Quality of Service • Economic and Financial	• Service Coverage • Water Consumption and Production • Non Revenue Water • Metering Practices • Pipe Network Performance • Cost and Staffing • Quality of Service • Billing and Collection • Financial Performance • Assets • Affordability • Process Indicators	• User Satisfaction • Community Management • Financial • Level of Service • Materials • Personnel • Equipment • Work Control	• Coverage • Water Consumption and Production • Unaccounted-for Water • Metering Practices • Pipe Network Performance • Cost & Staffing • Quality of Service • Billing & Collection • Financial performance • Capital Investment

From Table 2.1, the fundamental difference in approach for developing the themes of PIs by the various organizations is that the ADB, WHO and WB have recommended themes for developing countries, where the major concerns for water supply utilities are inefficient services and cost recovery. The IWA themes, on the other hand, cover a wider range of indicators to evaluate every aspect of the system. The PIs developed by the IWA are considered a major reference in the water industry. The main criticism of the PIs developed by the IWA are that there are too many indicators (130), too complicated to use and too general. However, the IWA maintains that the IWA system is no more complicated than any other PI system and that the choice of selecting the most appropriate PIs is entirely up to the user (Algere et al., 2006).

Although commendable, it is difficult to agree on a universal set of indicators and their detailed definitions since the different operating environment each faces can influence comparison between countries. The usefulness of an indicator, and its likelihood to be monitored, varies across countries. Even within the same country, the information sought for in PIs varies across different sectors. Policy makers look for highly aggregated information while utility managers want to see detailed activity costs. It can be thus drawn that PIs need to be site specific, addressing the needs and concerns of the locality that it serves.

2.1.2 Sustainability Indicators for water supply

As is common knowledge, the water resources worldwide are increasingly becoming stressed. Moreover, persistent concerns about climate change are most likely to aggravate the problem. A pressing issue for water supply utilities, therefore, is to incorporate these concerns in their planning process. However, there are very few organizations that focus on environmental issues that cause these concerns. Notable among these, is the National Water and Wastewater Benchmarking Initiative of Canada, whose theme areas encompass the following: sufficient capacity, reliable service and infrastructure, economic sufficiency, customer satisfaction, public health, environmental protection and employee safety (National Water and Wastewater Benchmarking Initiative 2009).

The Vewin Benchmark report of the Netherlands focuses on four themes, namely, water quality (drinking water quality and non compliance with norms), customer service (customer's report card and availability by telephone), environment (use of energy, dehydration, residue and nature management) and finance & efficiency (financial analysis at company and process level) (Vewin 2006).

Water UK, which includes water utilities in England, Wales, Scotland and Northern Ireland, has initiated a benchmarking exercise with special focus on sustainability indicators. The PIs measures cover five broad aspects, namely, customer experience, climate change and energy, natural resource protection, sustainable consumption & production and corporate governance, management & performance (Water UK 2009).

The German Association of Energy and Water Industries (Bundeverband der Energie – und Wasserwirtschaft e. V., Berlin and Brussels – BDEW), compare PIs of major water industries in Germany, whose thematic focus is on long-term security of supply, high water quality, high customer satisfaction, sustainable utilization of water resources and economic efficiency (BDEW 2010).

It is evident from the information provided in the previous two sections that there is a vast difference in thematic areas of benchmarking in developing and developed countries. While the water supply utilities in the developing countries still employ the traditional framework for PIs with a stronger emphasis on financial, operational and personnel indicators, there is increasing focus on environment and sustainability in the developed countries.

2.2 Background

2.2.1 General

Japan is an archipelago, made from four large islands and many other small islands, and around 400 islands are inhabited. Since Japan covers a wide range of latitude, the climate varies from cold zone (northern area), temperate monsoon zone (central area), to subtropical zone (southern area). The average temperatures in the northern, central and southern areas are 8, 15 and 22 °C respectively. This diverse climate range results in rich natural environment and ecosystem. Also, because of the diverse climate and topology, every region has different water environment. The average precipitation in Japan is 1,718 mm/year, higher than the world average (880 mm/year). Precipitations in the three areas are 1,029, 1,322, and 2,816 mm/year, respectively. Recently, local heavy rain and torrential showers have been occurring frequently.

After the introduction of the Waterworks Act in 1957, the water supply system in Japan has expanded rapidly, with the population coverage reaching 96.8% in 2008 from 30% in 1957. In doing so, approximately 789 multipurpose dams and 1878 single purpose dams were constructed. As a result, a steady supply of approximately 17.8 billion m^3/year has been established for domestic and industrial use. The domestic and industrial sector demand amounts to around 19% and 15% of the total demand respectively, while the rest of the demand is taken up by the agricultural sector. As of 2005, the combined demand for domestic and industrial use was 28.3 billion m^3, of which 75% is extracted from rivers and dams (Ministry of Land, Infrastructure, Transport and Tourism, MLITT, 2010). Lakes and groundwater contribute to fulfilling the rest of the demand. Although there are five government ministries associated with water resources in Japan, the Ministry of Health, Labor and Welfare (MHLW) is in charge of water supply for domestic use.

According to the Japan Waterworks Association (JWWA, 2008), as of 2007, there were 16,978 waterworks in Japan, and 93.8% of these had a service population of less than 5,000. According to the waterworks law, 'waterworks' are defined as water supply systems designed to supply more than 100 people with potable water through equipment such as pipes. However in the recent past, there has been an integration of small-scale water supply utilities for better productivity. The water utilities are classified as water supply businesses (managed by municipalities), bulk water supply businesses (managed by prefectures or a group of municipalities), private water supply and private water supply facilities, both of which are small scale suppliers. Japan boasts of excellent tap water quality. The treatment of water varies according to the quality of the source. Approximately 76% of the utilities use rapid sand filtration, while around 22% used disinfection without filtration. Since 1995, 22% of the utilities have adopted advanced treatment processes, which include ozone-GAC treatment coupled with membrane filtration. The average leakage rate for water supply utilities in Japan is around 8%, which suggests a well-monitored and efficient network (JWWA, 2008)

2.2.2 Future concerns for water supply utilities in Japan

2.2.2.1 Decreasing population trend

Although Japan has a well-developed and efficient water supply system, there are some concerns about the sustainable nature of the systems. Primary among these is the demographic trend of the Japanese population. As observed in Figure 2.1(a), the population in Japan has been on a decreasing trend since the early 2000's with a negative growth rate, and is expected to continue to decrease in the future (Statistics Bureau, 2007). With population decrease it is unlikely that Japan will experience water shortage in the future, especially given the nature and quality of the existing facilities. However, the facility utilization rate is likely to reduce, leading to precious financial funds being utilized for unnecessary purposes. Oki and Musiake (2009) point out that it will not be easy to maintain the current facilities under decreasing population.

The problem is compounded when the population of Japan is classified in different age groups. As seen in Figure 2.1(b), approximately 28% of the population in 2006 was above the age of 60, which is expected to increase to 39% and 47% in 2030 and 2055 respectively. A rapidly aging population could lead to lower employee productivity in water utilities, and influx of foreign workers to address the shortfall. This is likely to increase the financial strain on companies to ensure that the demand is met, and maintain and operate their systems efficiently.

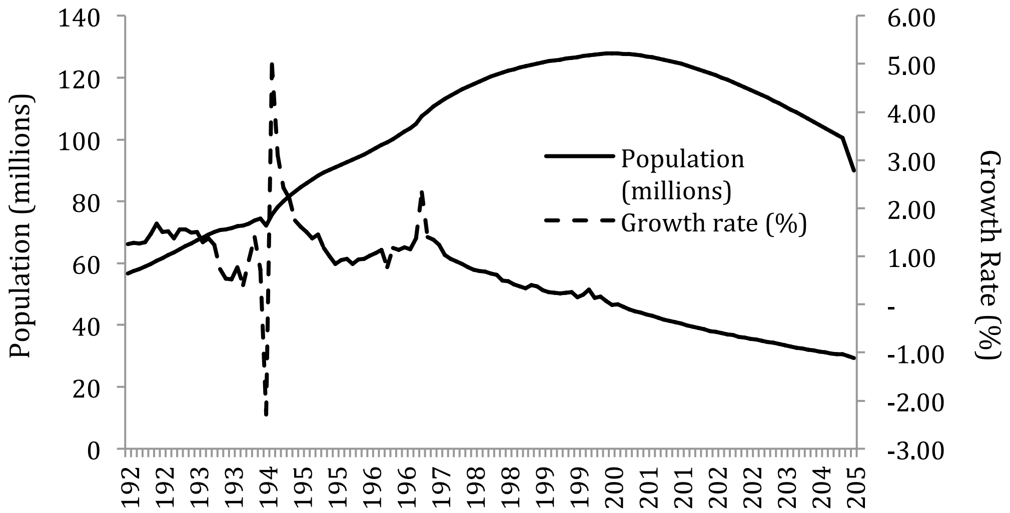


Figure 2.1(a): Current and projected population statistics of Japan

(Data Source: Statistics Bureau, Ministry of Public Management, Home Affairs, Post and Telecommunication, 2007)

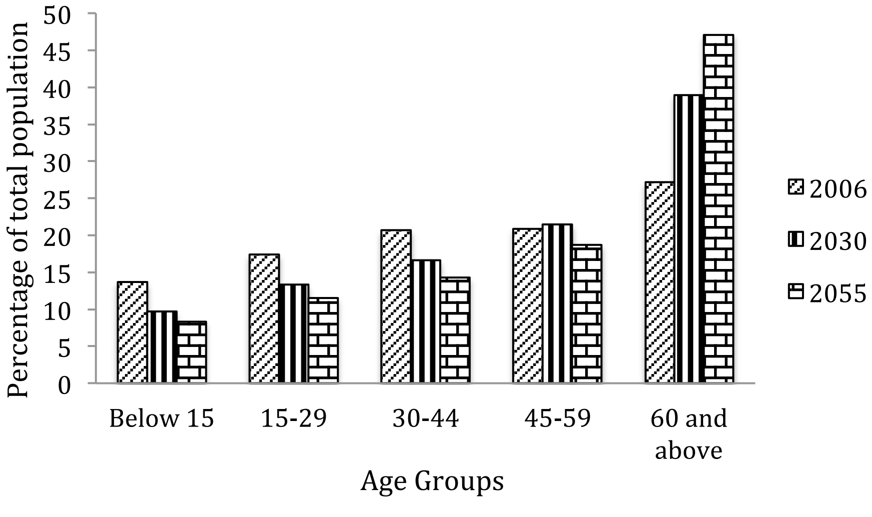


Figure 2.1(b): Current and projected population of Japan divided in age groups

(Data Source: Statistics Bureau, Ministry of Public Management, Home Affairs, Post and Telecommunication, 2007)

2.2.2.2 Small water utilities

More than 90% of the water utilities in Japan have a service population of less than 50,000, as observed in Figure 2.2. Owing to insufficient revenue collection and increasing depreciation cost, most of them are incapable of financially sustaining themselves. Additionally, increasing rehabilitation costs for upgrading old facilities further aggravate the problem. Tachikawa (2004) pointed out that the ratio of the amount available for investment to the amount required for rehabilitation is on an increasing trend, and is expected to reach 1 by 2025

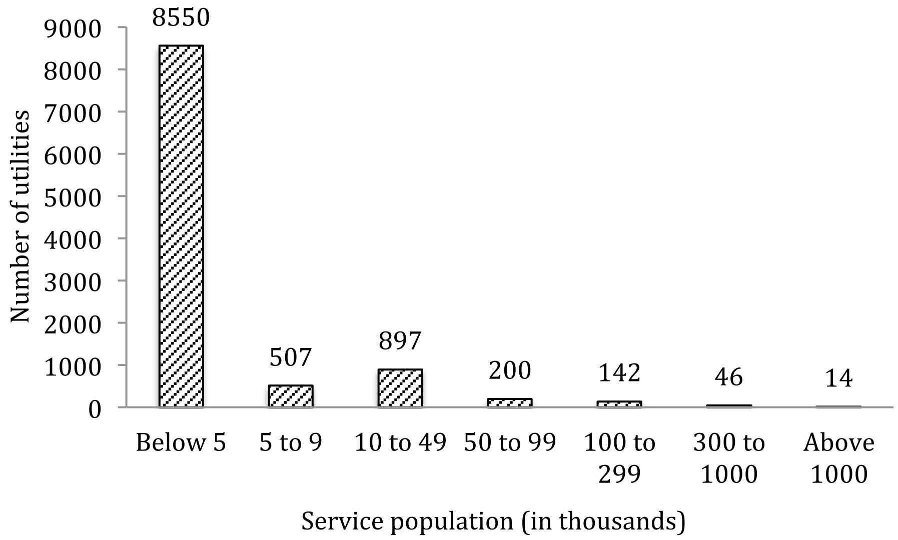


Figure 2.2: Service population of water supply utilities in Japan (Data Source: JWWA, 2004)

2.2.2.3 Climate change

Climate change is also expected to adversely impact water supply systems in Japan. The Ministry of Land, Infrastructure, Transport and Tourism (MLITT) have made estimates of the effects of climate change on the volume of precipitation. Based on the GCM20 (A1B) scenarios, an average increase in rainfall by a factor of 1.1 is expected across Japan in 2080-2089, compared to 1979-1998. Additionally, due to premature snowmelt, changes in the river flow regimes are a strong possibility. For most parts of the year, the future flow will be more than the current flow, suggesting periods of floods. However, during the crucial period between April and July, when larger amount of irrigation water is required for surface puddling of paddy crops, there will be a drastic reduction of flow in rivers (MLITT, 2010). To ensure food security, it is not unrealistic to assume high competition among water users during this season, possibly leading to unreliable water supply.

2.2.2.4 Increasing number of tap water quality complaints

From the water quality point of view, the current concerns are mainly governed by taste and odor issues. Complaints about chlorinous odor and taste in drinking water are on the rise with consumers becoming more sensitive to changes in water quality. Figure 2.3 shows the results of a survey carried out in Osaka by Itoh et al. (2007). The survey revealed that a majority of the respondents were hesitant in consuming water directly from the tap. Only around 22% of the male respondents and approximately 10% of the female respondents indicated their willingness to consume tap water directly.

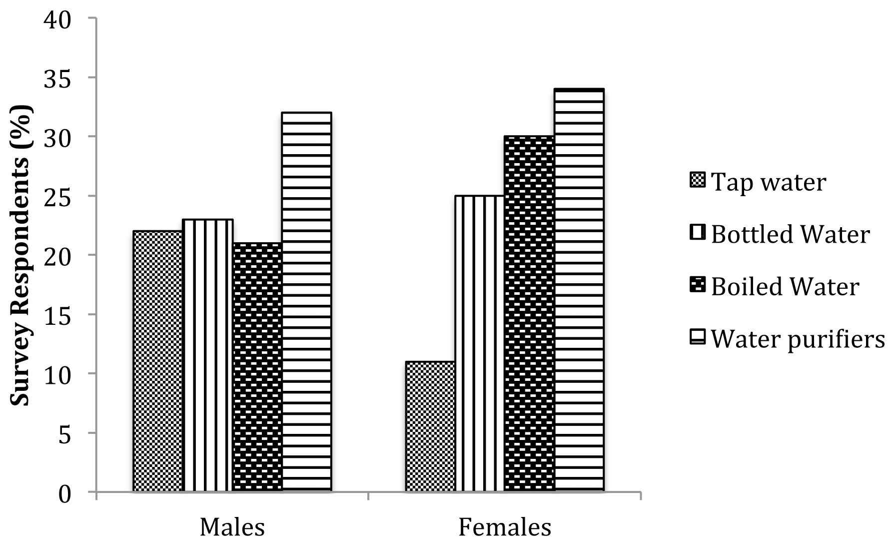


Figure 2.3: Drinking water habits for survey respondents in Osaka (Source: Itoh et al., 2007)

Most of the respondents (32% males and 34% females) preferred to use some kind of home purification system before consuming water while a significant number (24% males and 25% females) were in favor of using bottled water. This is a matter of grave concern because Osaka city has of one of the best tap water qualities in the entire country, which is still not enough to meet the consumer expectations.

2.3 Thematic objective and need of the study

A feasible way to investigate the impacts of climate and socioeconomic change on the operations of water supply utilities is to develop numerical models, which would be tested against a set of PIs under different scenarios of change. The selection of PIs for this purpose can be a delicate aspect for two reasons. First, most water utilities have a large number of PIs (e.g. 137 PIs for Japanese water utilities), and the inclusion of all of these into the evaluation models is an onerous task. Hence, there is a need to identify or develop key PIs, which can account for as much information as possible. Second, the PIs should be able to monitor not only the performance of the present supply system, but also evaluate potential future concerns (as explained in the previous section). A robust set of PIs is, therefore, required to make a rational evaluation of water supply systems in light of anticipated changes.

With a sound and effective performance indicator system in place, water supply utilities can dynamically work towards attaining high efficiency and the desired quality of service (Algere et al., 2006). The information elucidated from the evaluated PIs should ultimately help in decision making, thereby playing an important role in the planning and management of water supply utilities. However as seen in Figure 2.4, almost 25% of the utilities in Japan taking part in the benchmarking exercise carried in 2007, with the 137 PIs, had more than 50 missing entries. Only 4% of the utilities could provide information for all PIs, suggesting that evaluating and monitoring the current PIs is merely a statistical exercise, with no relevant contribution to planning and management.

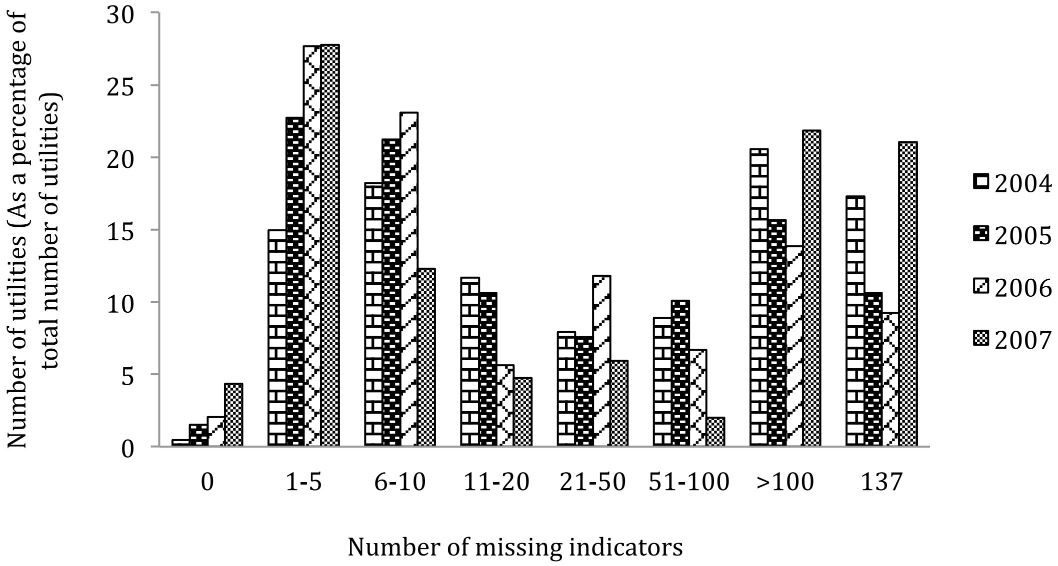


Figure 2.4: Trend for water supply utilities with incomplete information on PIs

The theme of this study is, thus, to revise the PI system and arrive at a reduced, relevant and practical structure that accounts for enough information required to rationally evaluate water supply systems in Japan for different scenarios of change. The study acknowledges that although difficult to evaluate, due to resource and financial constraints, the original indicators have been thoroughly developed with detailed consideration for all aspects of the supply system. Hence, instead of developing a new PI system, this study focuses on reducing the dimensionality in the existing system by selecting the more relevant and significant variables. To be able to be universally accepted, the choice of indicators should be based on scientific methods and techniques that are beyond debate. Hence, this study uses Principal Component Analysis (PCA), a dimension reduction statistical technique, to reduce the PI data set and classify it into smaller, manageable sets, whose suitability is then investigated in context of current and anticipated concerns that need to be addressed by the water utilities in Japan. Since PCA attempts to also extract the maximum variation from the original data set, the reduced set of indicators respects the original indicator system by retaining as much information as possible from it.

2.4 Principal Component Analysis (PCA)

PCA is a statistical technique that seeks to cluster intercorrelated variables into groups, in which each group exhibits a common trait. More specifically the goal of PCA is to “reduce the dimensionality of the original space and to give interpretation to the new space, spanned by a reduced number of new dimensions which are supposed to underlie the old ones” (Rietveld & Van Hout, 1993:254), or to “explain the variance in the observed variables in terms of underlying latent factors” (Habing, 2003:2)

2.4.1 Theory of PCA

PCA starts with the correlation/covariance matrix of the variables where the intercorrelation between variables is studied. Clustering together variables that have some ‘commonness’ can reduce the dimensionality of this matrix. Each cluster is called a ‘component’. The factors extracted can be visualized as axes along which the variables can be plotted. The clustering is performed by means of eigenvalue decomposition of the correlation/covariance matrix. The number of positive eigenvalues determines the number of dimensions needed to represent a set of scores without any loss of information. It also provides information about the amount of variance that is accounted for by the respective components. The eigenvectors corresponding to each eigenvalue are used as weighted coefficients to estimate the magnitude of the factors.

The steps in Principal Component Analysis are

- Calculate the mean and standard deviation of the variables in the data set

- Calculate the correlation or covariance between the variables

$$r = \frac{n\sum_{i=1}^{n} X_i Y_i - \sum_{i=1}^{n} X_i \sum_{i=1}^{n} Y_i}{\sqrt{\{n(\sum_{i=1}^{n} X^2) - (\sum_{i=1}^{n} X)^2\}\{n(\sum_{i=1}^{n} Y^2) - (\sum_{i=1}^{n} Y)^2}}$$

$$\text{Cov}(X,Y) = \frac{\sum_{i=1}^{n} (X_i - \overline{X})(Y_i - \overline{Y})}{n}$$

Where Xi,Yi = raw variables

$\overline{X}$ and $\overline{Y}$ = the means of the variables n = sample size of the variables

- Calculate the eigenvalues and the eigenvectors of the correlation/covariance matrix

$$\left[\lambda I - A\right]\overrightarrow{E_v} = 0$$

Where λ = Eigenvalue

I = Identity matrix

A= Correlation/covariance matrix

$\overrightarrow{E_v}$ = Eigenvector

- The Principal components/factors are given by the equation

$$Zn = \sum_{i=1}^{n} \overrightarrow{E}_{vi} X_i$$

Where Zn = Magnitude of the Principal Component

$\overrightarrow{E_{vi}}$ = Eigenvector

Xi = Variables

- The component corresponding to the largest eigenvalue is the first Principal component, which also extracts the maximum variance from the data. Similarly, the second largest eigenvalue forms the second component, and so on.

2.4.2 PCA Glossary

Component/Factor loading: is the correlation between the variables and the extracted components/factors. Loading reflects only the relative importance of the variable within a component/factor and does not reflect the importance of the component itself (Davis, 1986).

Communality: of a variable is the variance in that variable which has been extracted by the components. Thus, if the communality of a variable is high, the extracted components/factors account for a bigger proportion of the variable's variance suggesting that the variable is reflected well in the analysis.

Component/Factor scores: are the scores of each case (exemplar) on the components/factors and is calculated by

Σ Standardized score for the case x corresponding component/factor loading of the variable

Scree plot: is a graph of each eigenvalue (ordinate) against the component/factor with which it is associated (abscissa)

Rotation: is a process of rearranging the pattern of component/factor loadings along the numerous factors/components so that component/factor interpretation becomes easier. Rotation does not alter the variance in the data but merely spreads it out more for easier interpretation. There are two basic types of rotation – orthogonal and oblique. Orthogonal rotation is when a factor is rotated through an angle of 90° suggesting there is no correlation between the factors/components. In oblique rotation there is no such constraint.

Component transformation matrix: describes the specific rotation used to arrive at a final solution.
Thus,

Component/factor loading matrix X component/factor transformation matrix = Rotated component/factor matrix

Bartlet's Sphericity test:
This a test performed to check the hypothesis that the variables used are uncorrelated in the population. In other words, the hypothesis suggests that the population correlation matrix is an identity matrix suggesting that each variable is perfectly correlated to itself but has no correlation with the other variables. The test is performed as follows

- Calculate the determinant (S) of the matrix of products and cross products from which the intercorrelation matrix is derived

- The determinant S is converted to chi-squared statistic and tested for significance.

$$\lambda^2 = -\left[(n-1) - \frac{1}{6}\left(2p + 1 + \left\{\frac{2}{p}\right\}\right)\right]\left[\ln|S| + p\ln\left(\frac{1}{p}\right)\sum I_j\right]$$

Where n = number of variables

p = number of components/factors

I_j = jth eigenvalue of S

df = degrees of freedom = (p-1)(p-2)/2

The significance level should be less than 0.005, to ensure that PCA/FA would be appropriate, for 95% confidence.

Keiser Meyer Olkin (KMO) measure of sampling adequacy:

This is an index to test whether there is enough data required to perform PCA satisfactorily. The equation to describe the KMO static is depicted below

$$\text{KMO} = (\sum\sum r_{ij}^2)/(\sum\sum r_{ij}^2 + (\sum\sum a_{ij}^2)$$

Where r_{ij}^2 = coefficient of determination between two variables

a_{ij}^2 = partial correlation of the two variables

KMO values in the 0.90s are considered marvelous; in the 0.80s as meritorious; in the 0.70s as middling; in the 0.60s as mediocre; in the 0.50s as miserable and below 0.50 as unacceptable (Field, 2005). The value indicates the proportion of variance that is common variance.

2.5 Data Collection

For the purpose of this study, the PIs of major water utilities in Japan were considered for analysis. In 2005, guidelines for the management and assessment of a drinking water supply services were developed by the Japan Water Research Center (JWRC), which included a set of performance indicators. Referring to the PIs recommended by various international organizations already mentioned earlier, and discussions with water utility managers, 137 PIs were developed. The PIs are categorized into five themes, namely, safety, stability, sustainability, environment and global cooperation (JWWA 2005). PI data was collected from the JWWA, which collects PI information from utilities all over Japan, for the years 2004 through 2007, which was available for 177 water utilities from 2004 to 2006 and 199 utilities in 2007. Appendix 1 presents the entire range of PIs and explanatory variables, as recommended by the JWRC.

2.6 Research methodology

To reduce the data set with minimum loss of information and identify the more important variables that measure a common trait, this study employed PCA. PCA is a multivariate statistical technique that reduces the dimensionality of a data set containing interrelated variables, while retaining as much as possible of the variation present in the data set. PCA uses eigenvalue decomposition of the correlation/covariance matrix of the data set and transforms the data into a new set of fewer variables, called Principal Components, which are uncorrelated, and which are ordered so that the first few retain most of the variation present in all of the original data (Jollife, 2002; Kline, 1994).

In developing a performance indicator system, practical studies have pointed out the fact that it is better to consider fewer crucial variables, instead of including all variables since doing so may influence the phenomenon being characterized (Coulibaly and Rodriguez, 2004; Ioris et al., 2008). To reduce the data set with minimum loss of information and identify the more important variables that measure a common trait, this study employed PCA, which is a statistical technique that seeks to account for patterns of co-linearity in the data set. The analysis was performed with IBM SPSS Statistics base 18.0. The methodology used for the analysis is depicted as a flow diagram in Figure 2.5

For the purpose of this study, the PIs of major water utilities in Japan were considered for analysis. PI data was collected from the JWWA for the years 2004 through 2007, which was available for 177 water utilities from 2004 to 2006, and 199 utilities in 2007. The initial sample size of the data set included 730 water utilities (called cases henceforth), over a 4-year period, and 137 PIs (called variables henceforth). However, as pointed out before, there were numerous missing entries. Very few utilities provided information pertaining to certain PIs suggesting that these PIs are either difficult to measure or redundant in the opinion of the managers of those utilities. Similarly some utilities failed to provide information corresponding to most of the PIs implying lack of resources/desire of the utilities to perform the exercise. After omitting the missing data, the number of cases and variables was brought down to 132 and 113 respectively. Since the foundation of this study is based on extracting the maximum variance from the original PIs, efforts were taken to omit as few variables as possible, in the process rendering a small sample size and case to variable ratio.

There is no definite rule to ascertain the minimum sample size required to perform PCA and the numerous recommendations made by researchers vary. E.g. some suggest a minimum sample size of 100 (Gorsuch, 1983; Kline, 1979), or a case to variable ratio ranging from 10:1 (Velicer and Fawa, 1998) to 2:1 (Kline, 1979). Costello and Osborne (2005) surveyed two year's PsychINFO articles and reported that 14.7% of the studies used a case to variable ratio of 2:1 or less. Favorable results were obtained with case to variable ratio as less as 1.2:1 (Barret and Kline, 1981).

To check whether the smaller sample size affected the results, the PCA was carried out in two stages. First, a preliminary exploratory analysis was performed with all the variables and cases (full-set), and the components were extracted. The KMO value was checked for sampling adequacy. If this value was above 0.5, the data set was considered satisfactory for the analysis. Similarly, only if the Bartlett's statistics (chi-squared) was less than the significance level (0.005 for 95% confidence), further analysis was performed. Outliers were detected from the sample set, and removed because their presence can affect the correlation coefficients significantly. The method used for detecting outliers has already been described in Figure 2.5.

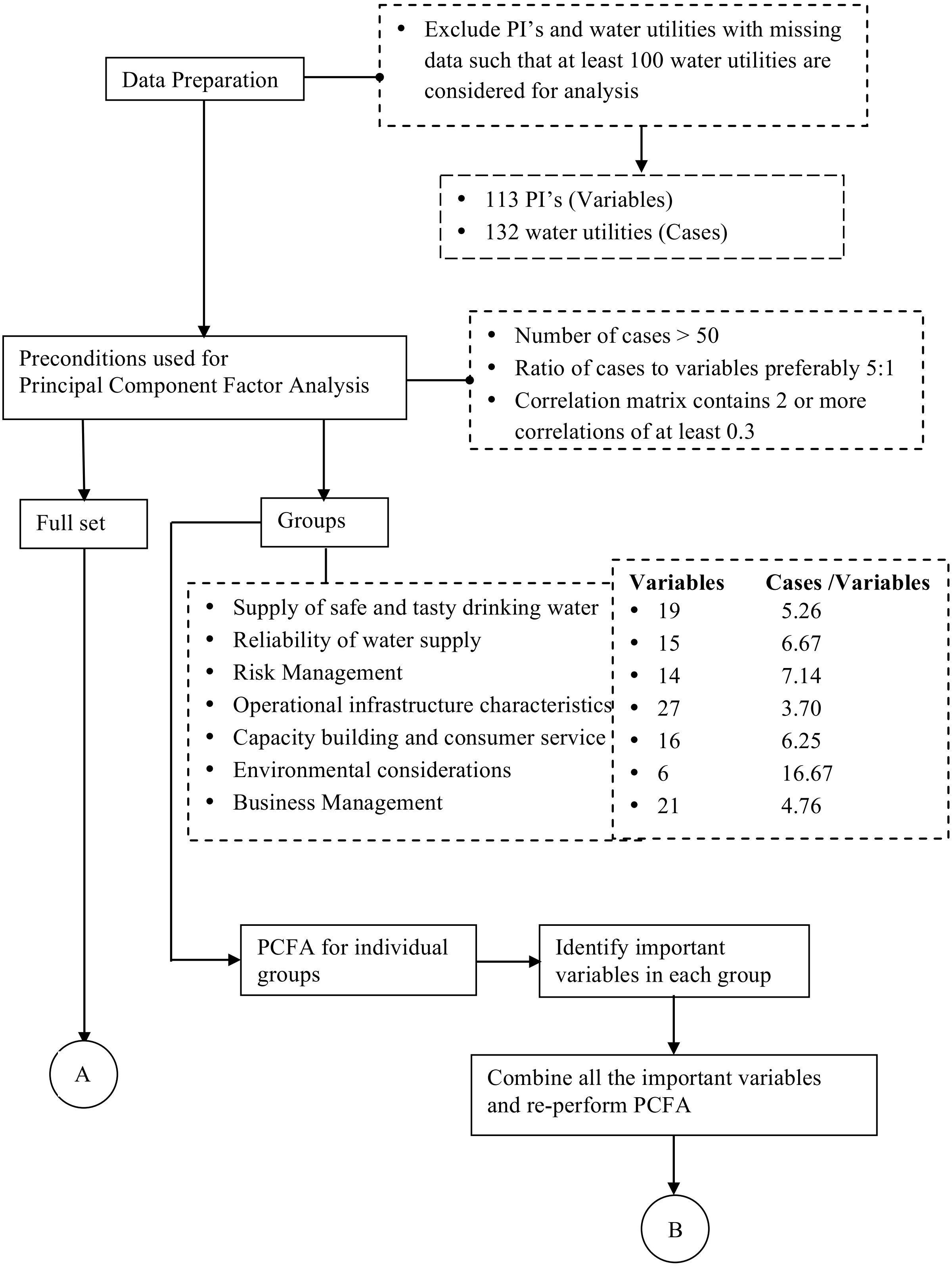


Figure 2.5: Schematic of research methodology to develop 9-component performance indicator system

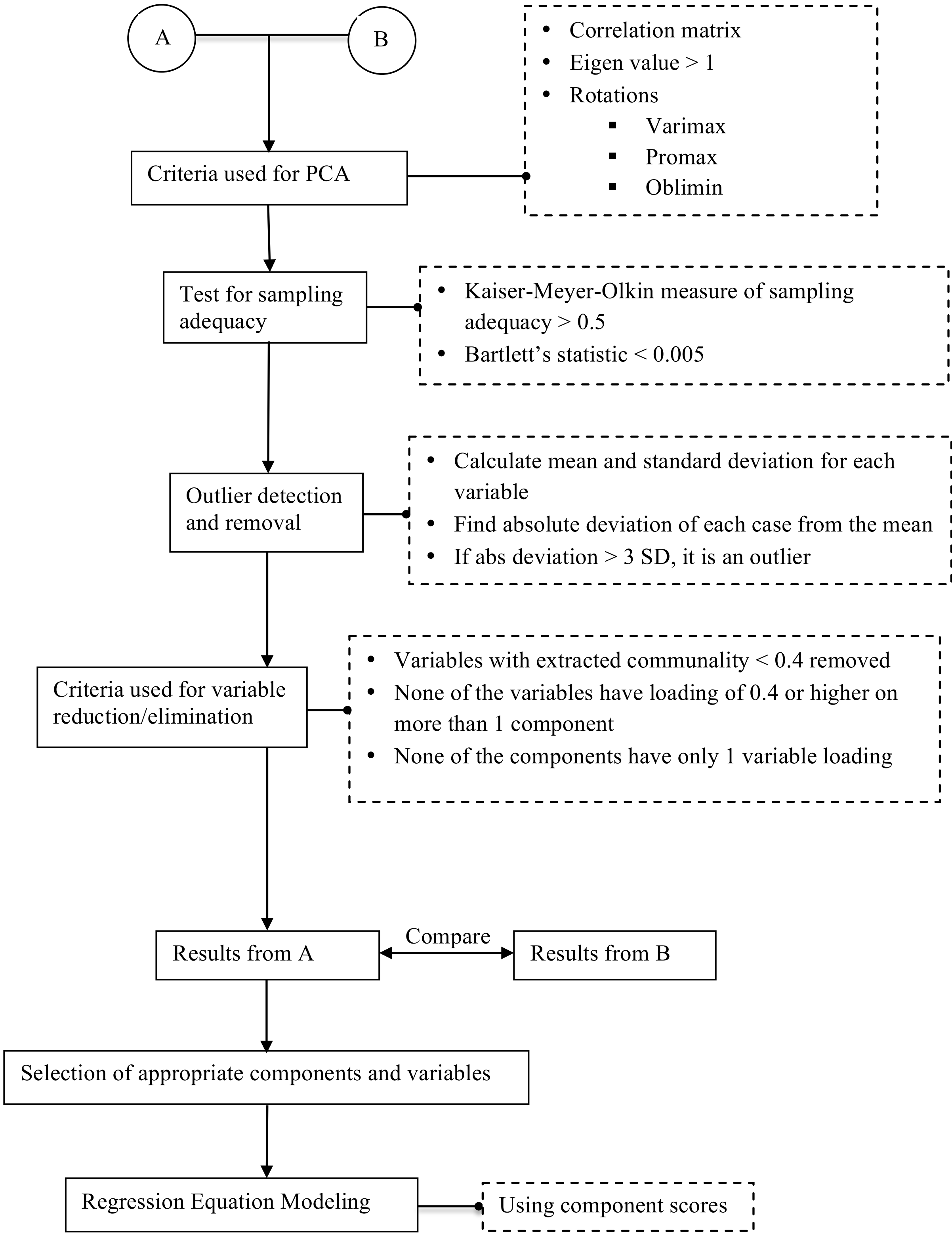


Figure 2.5: Schematic of research methodology to develop 9-component performance indicator system continued…

A detailed study was then conducted on the variables contributing to each component to identify commonness of information elucidated. During the analysis, variables with extracted communality less than 0.4 were removed, since such variables will struggle to load on any component. To avoid cross loading, the variables with loadings of 0.5 or higher on more than 1 component were discarded. High loading variables are understandably crucial but if a variable loads highly on two or more components (cross loading), interpretation of the components becomes difficult and hence these variables should not be included in the analysis, especially if there are other variables loading strongly onto the components (Costello and Osborne, 2005).

In this study, a variable with loading of more than 0.5 was considered to make a significant contribution to the components. Rule of thumb recommends this value to be 0.32 (Tabachnick and Fidell, 2001). However, this study used a higher value since the analysis had many strong loading variables. Components with fewer than three variables were not considered since they are usually weak and unstable (Costello and Osborne, 2005). The commonly used Kaiser eigenvalue rule (Kaiser, 1960) was used to select the number of principal components for further analysis. According to this rule, only factors with eigenvalues greater than one are to be retained for further analysis.

To have a better understanding of the information elucidated by the components, varimax rotation was performed. The goal of rotation is to simplify and clarify the data structure. Rotation cannot improve the basic aspects of the analysis, such as the variance extracted from the items, but merely rearranges the data structure by increasing the loading of variables on one component and reducing it on others. Among the different rotation techniques, varimax rotation is the commonest (Costello and Osborne, 2005). Since varimax rotation is orthogonal in nature where the components are not correlated, promax rotation was performed to explore the relationship between components, if any. This is significant in the interpretation of components and can provide useful insight into identifying whether or not there are common features that contribute to the components.

Alternately, a separate confirmatory analysis was performed with contributing variables of two components at a time (group-sets) (8-10) and 5-8 discarded variables (65), in a cyclic pattern. The aim was to ensure that the case to variable ratio stayed above 5, and to check if, due to the small sample size, any discarded variables that could have contributed to the components were missed out. The results from the 'full-set' and 'group-set' analyses were compared, based on which the appropriate components and variables were finalized.

Finally, regression equations for each component were developed using the component scores. The internal consistency of variables contributing to a component was examined by estimating the intercorrelation between contributing variables and developing scatter plots of components versus contributing variables.

2.7 Results and Discussion

2.7.1 Extraction of Principal Components

Results of the PCA with the 'full-set analysis' and 'group-sets analysis', using varimax rotation, are presented in Tables 2.2 and 2.3. Varimax is the most commonly used rotation technique, which maximizes the sum of the variances of the squared coefficients within each eigenvector, and the rotated axes remain orthogonal. As the angle of 90° between the axes directly corresponds to the uncorrelatedness of the factors, this implies that the rotated components are uncorrelated as well.

As mentioned earlier, the 'full-set analysis' is the analysis using all the variables and cases at the same time. The 'group-set' analysis is the analysis in stages where the variables of 2-3 components (obtained from the full set analysis) are tested along with 5-8 randomly picked variables. The group-set analysis was performed to cross check the results of the full-set analysis because the case to variable ratio in the full set analysis was below 5.

Upon comparing Tables 2.2 and 2.3, it can be observed that in both cases the same variables load on to the respective components, although the magnitude of loadings vary. More importantly, the pattern of loadings (negative and positive) is similar in both cases. This indicates that even with a low case to variable ration in the full-set analysis, reliable results are obtained. Hence, it can be suggested that the results are identical in both cases. Since the 'full-set analysis' is easier to perform, because the analysis is performed only once, all further work was been carried out with the 'full-set' data.

Further analysis with promax and oblimin rotations was performed using the pattern and structure modules to check for any differences. Both promax and oblimin are oblique rotation techniques which allow for some correlation between the components. The structure matrix holds the correlations between each variable and each factor, while the pattern matrix holds the beta weights to reproduce variable scores from factor scores. Tables 2.4 through 2.7 present the results of the analyses. The results obtained from promax and oblimin rotations in Tables 2.4 through 2.7 are identical to the ones obtained with varimax rotation – the same 9 components are extracted, and the same variables load onto the components with promax rotation as with those of varimax rotation albeit with different component scores, suggesting consistency in results. Hence, the outcome of 'full-set' with varimax rotation has been considered as the final result and subsequent analysis has been based on this result.

Table 2.2: 'Full-set analysis', with varimax rotation

Component	Variables	Loading
1	Water supply revenue	0.931
	Price for households using up to $20m^3$ water	0.913
	Water production cost	0.898
	Price for households using up to $10m^3$ water	0.742
2	Staff salary as ratio of total revenue	-0.877
	Water revenue per employee	0.833
	Amount of water supplied per unit staff	0.819
	Meters per unit staff	0.801
	Average work experience ratio	-0.744
3	Current account balance ratio	0.935
	Total balance ratio	0.920
	Revenue to cost ratio of water supply	0.879
	Operating balance ratio	0.806
4	Number of international collaborations	0.950
	Development expense ratio	0.871
	Requests for information made by consumers	0.845
5	Percentage of outstanding revenue bonds	0.928
	Rate of interest for revenue bonds	0.908
	Net worth to capital	-0.696
	Redemption rate of revenue bonds	0.615
6	Greenhouse gases emissions	-0.879
	Power consumption	-0.843
	Energy consumption	-0.841
7	TOC concentration as ratio of permissible TOC	-0.810
	THM concentration as ratio of permissible THM	-0.779
	Water without chlorinous odor	0.738
	Water without musty odor	0.607
8	Water vehicles ratio	0.907
	Pipeline rehabilitation rate	0.760
	Drinking water storage per capita in event of emergency	0.717
9	Distribution reservoir seismic facility rate	0.887
	Water treatment plant seismic facility rate	0.842
	Pump station seismic facility rate	0.669

Table 2.3: 'Group-set analysis' with varimax rotation

Component	Variables	Loading
1	TOC concentration as ratio of permissible TOC	0.846
	Trihelomethane concentration as ratio of permissible THM	0.841
	Water without chlorinous odor	-0.824
	Water without musty odor	-0.796
2	Distribution reservoir seismic facility rate	0.441
	Water treatment plant seismic rate	0.423
	Pump station seismic facility rate	0.368
3	Current account balance ratio	0.951
	Total balance ratio	0.938
	Revenue to cost ratio of water	0.887
	Operating balance ratio	0.873
4	Price for households using up to 20m^3 water	0.958
	Water supply revenue	0.927
	Water production cost	0.900
	Price for households using up to 10m^3 water	0.829
5	Water revenue per employee	0.960
	Staff salary as ratio of total revenue	-0.883
	Amount of water supplied per unit staff	0.803
	Meters per unit staff	0.756
6	Development expense ratio	0.843
	Number of international collaborations	0.820
	Requests for information made by consumers	0.780
7	Water vehicles ratio	0.867
	Pipeline rehabilitation rate	0.725
	Drinking water storage in event of emergency	0.698
8	Greenhouse gases emissions	-0.824
	Energy consumption	-0.815
	Power consumption	-0.800
9	Percentage of outstanding revenue bonds	0.876
	Net worth to capital	-0.812
	Rate of interest for revenue bonds	0.789
	Redemption rate of revenue bonds	-0.675

Table 2.4: PCA with promax pattern rotation

Component	Variables	Loading
1	Water supply revenue	.989
	Water production cost	.963
	Price for households using up to 10m^3 water	.668
	Price for households using up to 20m^3 water	.925
2	Water revenue per employee	.899
	Staff salary as ratio of total revenue	-.917
	Average work experience ratio	-.705
	Amount of water supplied per unit staff	.796
	Meters per unit staff	.795
3	Operating balance ratio	.778
	Current account balance ratio	.966
	Total balance ratio	.953
	Revenue to cost ratio of water	.859
4	Development expense ratio	.909
	Information disclosure	.886
	Number of international relations	.999
5	Corporate bond interest rate of return for water supply	.919
	Percentage of outstanding revenue bonds	.964
	Net worth to capital ratio	-.678
6	Power consumption	.878
	Energy consumption	.873
	Greenhouse gases emissions	.955
7	Achievement of water in terms of musty odor	-.607
	Achievement of water in terms of chlorinous odor	-.739
	THM concentration as ratio of permissible THM	.787
	TOC concentration as ratio of permissible TOC	.862
8	Drinking water storage per capita in event of disaster	.718
	Pipeline rehabilitation rate	.782
	Water vehicles ratio	.915
9	Water facilities seismic rate	.863
	Pump station seismic facility rate	.651
	Distribution reservoir seismic facility rate	.899

Table 2.5: PCA with promax structure rotation

Component	Variables	Loading
1	Water supply revenue	.947
	Water production cost	.897
	Price for households using up to 10m^3 water	.807
	Price for households using up to 20m^3 water	.942
2	Water revenue per employee	.810
	Staff salary as ratio of total revenue	-.869
	Average work experience ratio	-.768
	Amount of water supplied per unit staff	.840
	Meters per unit staff	.810
3	Operating balance ratio	.841
	Current account balance ratio	.938
	Total balance ratio	.919
	Revenue to cost ratio of water	.886
4	Development expense ratio	.872
	Information disclosure	.851
	Number of international relations	.945
5	Corporate bond interest rate of return for water supply	.941
	Redemption rate of revenue bonds	.639
	Percentage of outstanding revenue bonds	.948
	Net worth to capital ratio	-.745
6	Power consumption	.926
	Energy consumption	.921
	Greenhouse gases emissions	.915
7	Achievement of water in terms of musty odor	-.634
	Achievement of water in terms of chlorinous odor	-.780
	THM concentration as ratio of permissible THM	.800
	TOC concentration as ratio of permissible TOC	.802
8	Drinking water storage per capita in event of disaster	.734
	Pipeline rehabilitation rate	.748
	Water vehicles ratio	.914
9	Water facilities seismic rate	.840
	Pump station seismic facility rate	.695
	Distribution reservoir seismic facility rate	.907

Table 2.6: PCA with oblimin pattern rotation

Component	Variables	Loading
1	Corporate bond interest rate of return for water supply	-.908
	Redemption rate of revenue bonds	-.600
	Percentage of outstanding revenue bonds	-.941
	Net worth to capital ratio	.687
2	Operating balance ratio	.772
	Current account balance ratio	.944
	Total balance ratio	.930
	Revenue to cost ratio of water	.844
3	Water revenue per employee	.874
	Staff salary as ratio of total revenue	-.901
	Average work experience ratio	-.692
	Amount of water supplied per unit staff	.776
	Meters per unit staff	.765
4	Water supply revenue	.937
	Water production cost	.915
	Price for households using up to $10m^3$ water	.646
	Price for households using up to $20m^3$ water	.880
5	Development expense ratio	.871
	Information disclosure	.848
	Number of international relations	.957
6	Drinking water storage per capita in event of disaster	.721
	Pipeline rehabilitation rate	.761
	Water vehicles ratio	.899
7	Water facilities seismic rate	.820
	Pump station seismic facility rate	.650
	Distribution reservoir seismic facility rate	.865
8	Achievement of water in terms of musty odor	.622
	Achievement of water in terms of chlorinous odor	.724
	THM concentration as ratio of permissible THM	-.747
	TOC concentration as ratio of permissible TOC	-.804
9	Power consumption	.871
	Energy consumption	.869
	Greenhouse gases emissions	.923

Table 2.7: PCA with oblimin structure rotation

Component	Variables	Loading
1	Corporate bond interest rate of return for water supply	-.945
	Redemption rate of revenue bonds	-.653
	Percentage of outstanding revenue bonds	-.948
	Net worth to capital ratio	.722
2	Operating balance ratio	.820
	Current account balance ratio	.953
	Total balance ratio	.938
	Revenue to cost ratio of water	.889
3	Water revenue per employee	.847
	Staff salary as ratio of total revenue	-.890
	Average work experience ratio	-.728
	Amount of water supplied per unit staff	.822
	Meters per unit staff	.803
4	Water supply revenue	.949
	Water production cost	.908
	Price for households using up to $10m^3$ water	.766
	Price for households using up to $20m^3$ water	.930
5	Development expense ratio	.885
	Information disclosure	.860
	Number of international relations	.958
6	Drinking water storage per capita in event of disaster	.716
	Pipeline rehabilitation rate	.765
	Water vehicles ratio	.915
7	Water facilities seismic rate	.850
	Pump station seismic facility rate	.695
	Distribution reservoir seismic facility rate	.911
8	Achievement of water in terms of musty odor	.638
	Achievement of water in terms of chlorinous odor	.766
	THM concentration as ratio of permissible THM	-.797
	TOC concentration as ratio of permissible TOC	-.812
9	Power consumption	.944
	Energy consumption	.935
	Greenhouse gases emissions	.928

2.7.2 Inspecting orthogonality of components

Orthogonal components indicate that the components are independent of each other. The objective of the study is to develop a Performance Indicator system, which can evaluate and monitor different aspects of the supply system. Overlap of information is not desirable as that could lead to ambiguity and could result in biased weightage of certain variables.

To check the orthogonality of components, the correlation between components using promax rotation was calculated, since promax rotation allows components to be correlated and thus non-orthogonal. Table 2.8 presents the correlations of the components extracted by promax pattern rotation. The relevant analysis has already been presented in Table 2.4

Table 2.8: Component correlations using promax pattern rotation for PI analysis

Component	1	2	3	4	5	6	7	8	9
1	1	-0.05	0.14	-0.14	0.11	0.12	-0.20	-0.08	0.10
2		1	0.03	-0.07	-0.12	-0.06	0	0.02	0
3			1	0.06	0.13	0.21	-0.09	-0.09	0.03
4				1	-0.26	-0.07	0.08	-0.13	0.01
5					1	0.04	-0.19	0.04	0.05
6						1	0.14	-0.01	-0.11
7							1	-0.02	-0.01
8								1	-0.02
9									1

As observed in Table 2.8, there is very little to negligible correlation between the components suggesting that the components are orthogonal in nature with no overlap of information. This indicates that the 9 components extracted are independent of each other. Hence, the results with varimax rotation have been considered for further analysis.

2.7.3 Component Interpretation

As seen in the previous section, the PCA results do not vary much across the different sets (full-set and group-sets) and rotations (varimax and promax). Also as mentioned before, the outcome of ‘full-set’ with varimax rotation has been considered as the final result. Table 2.9 presents the relevant components, identified from the PCA, which are proposed as pertinent PIs to evaluate the performance of small water supply systems in Japan. The components were extracted based on the current and future concerns that the water supply utilities in Japan are likely to face, discussed in the subsequent section. The PCA reduced the original set of 113 variables to 9 components consisting of 33 contributing variables (9-component performance indicator system). All contributing variables load strongly onto the respective components, and have high values of extracted communality, thereby mitigating the concerns caused by the small sample size. Also presented in Table 2.9 is the variance of the original data set extracted by each of the 9 components, indicating a total of 64.9% variance extracted by the 9 components together. The explanatory notes describing the quantification of the contributing variable can be revisited in Appendix 1.

The PCA results, as seen in Table 2.9, yielded 9 components and hence this system has been called a **"9-Component Performance Indicator System (9-cPIS)".** Details of each component are hereafter discussed in this section.

(1) The first component has been called **"Economic Value of Water",** which supports the notion outlined in Dublin Principle 4 (UNCED, 1992) that "water has an economic value in all it's competing uses and should be recognized as an economic good". Water supplied by public agencies is usually priced at its average delivery cost rather than its value to producers. As a result water is rarely priced at its marginal value (Young, 2005). A fair *Economic Value of Water* leads to making informed choices about the use, conservation and allocation of water. Water having an appropriate price will give a clear signal to the users that water is indeed a scarce good that should be used sparingly (Zaag and Savenije, 2006). The 'water supply revenue' and 'water production cost' are two variables that understandably have a large bearing on the *Economic Value of Water*. Since Japan has a stepped water tariff system, in which the unit price for higher consumption is more than that for lower consumption, it can thus be inferred that the 'water price stipulated for households using up to 20m^3/month' is more likely to enhance *Economic Value of Water* than the 'water price for households using up to 10m^3/month', as seen by the variable loadings in Table 2.9. With variation in the amount and pattern of rainfall in the future, the water production cost is very likely to increase, thereby affecting the other contributing variables, and hence making *Economic Value of Water* an important PI to assess the performance of the system.

(2) The second component **"Employee Productivity"** is an important PI in context of Japan's demographical pattern. Japan has a rapidly aging population with 20.1% of the population above the age of 65 as of 2005, which is expected to increase to 31.8% by 2030. Moreover, the overall population shows a decreasing trend and is projected to decrease to under 100 Million in 2046 from the current 127.3 Million (Kaneko et al., 2007). Given that the strength of the work force is likely to decrease, it will be important for utilities to arrive at an acceptable level of work output from its employees ('water revenue per employee', 'amount of water supplied per unit staff' and 'meters per unit staff'), without compromising on the efficiency of supply.

Table 2.9: Results of Principal Component Analysis using varimax rotation

Variable code	Contributing Variables	Loading	Extracted Comm.	Comp Score	Component Name
EV_1	Water supply revenue	0.931	0.961	0.264	Economic Value of Water
EV_2	Water fee for HH using up to $20m^3$ per month	0.913	0.940	0.241	
EV_3	Water production cost	0.898	0.954	0.253	
EV_4	Water fee for HH using up to $10m^3$ per month	0.742	0.863	0.152	
EP_1	Staff salary as ratio of total revenue	-0.877	0.947	-0.256	Employee Productivity
EP_2	Water revenue per employee	0.833	0.933	0.244	
EP_3	Amount of water supplied per unit staff	0.819	0.929	0.206	
EP_4	Meters per unit staff	0.801	0.863	0.201	
EP_1	Average work experience ratio	-0.744	0.885	-0.187	
FS_1	Current account balance ratio	0.935	0.955	0.280	Financial Sustainability
FS_2	Total balance ratio	0.920	0.951	0.275	
FS_3	Revenue to cost ratio of water supply	0.879	0.916	0.232	
FS_4	Operating balance ratio	0.806	0.947	0.207	
AM_1	Number of international collaborations	0.950	0.942	0.285	Adaptive Management
AM_2	Development expense ratio	0.871	0.817	0.252	
AM_3	Requests for information made by consumers	0.845	0.773	0.247	
PIN_1	Percentage of outstanding revenue bonds	0.928	0.943	0.341	Private Investment
PIN_2	Rate of interest for revenue bonds	0.908	0.946	0.313	
PIN_3	Net worth to total capital	-0.696	0.871	-0.232	
PIN_4	Redemption rate of revenue bonds	0.615	0.674	0.199	
GWS_1	Greenhouse gases emissions	-0.879	0.899	-0.366	Green Water Supply
GWS_2	Power consumption	-0.843	0.969	-0.319	
GWS_3	Energy consumption	-0.841	0.943	-0.323	
$CSWQ_1$	TOC as ratio of permissible TOC	-0.810	0.795	-0.315	Consumer Satisfaction for Water Quality
$CSWQ_2$	THM as ratio of permissible THM	-0.779	0.787	-0.281	
$CSWQ_3$	Water without chlorinous odor	0.738	0.791	0.288	
$CSWQ_4$	Water without musty odor	0.607	0.640	0.263	
ERI_1	Water vehicles ratio	0.907	0.890	0.335	Emergency Response Index
ERI_2	Pipeline rehabilitation rate	0.760	0.641	0.284	
ERI_3	Drinking water storage in event of emergency	0.717	0.843	0.286	
ERS_1	Distribution reservoir seismic facility rate	0.887	0.937	0.351	Earthquake Resistant Water Supply
ERS_2	Water treatment plant seismic facility rate	0.842	0.894	0.334	
ERS_3	Pump station seismic facility rate	0.669	0.797	0.271	

HH=Households; TOC =Total Organic Carbon; THM =Trihalomethanes

Additionally, a reduced work force may result in increased salaries and hiring of foreign personnel, which usually results in a higher proportion of the revenue spent on remuneration, thereby causing the *Employee Productivity* to drop ('s*taff salary as ratio of total revenue'),* as indicated by the negative loading in Table 2.9. An aging population would result in older employees with more number of years as work experience ('av*erage work experience ratio'*). Since the salaries in Japan are usually based on seniority, it follows that that more revenue will be spent on salaries, resulting in reduced *Employee Productivity* (Negative loading of this variable in Table 2.9).

(3) The third component **"Financial Sustainability"** of a project, as defined by the ADB (1997), refers to a condition that "the project will have sufficient funds to meet all its resource and financing obligations, whether these funds come from user charges or budget sources; will provide sufficient incentive to maintain the participation of all project participants; and will be able to respond to adverse changes in financial conditions". Hence, to achieve *Financial Sustainability*, this essentially means that the unit price of supplied water should exceed the unit production cost ('revenue to cost ratio of water supply'). Further the revenues generated should be more than the cost incurred. For a typical water supply utility in Japan, there are three components of revenue and corresponding costs – operating revenue (revenue obtained through water bills only), non-operating revenue (revenues generated from sales of bonds etc.) and acquisition revenue (revenues generated by sales of land or assets). Accordingly, to ensure *Financial Sustainability*, it is important for utilities to maximize the 'operating balance', 'current account balance' and 'total balance ratios', respectively. The uncertain nature of water availability and quality in the future are likely to have profound implications on *Financial Sustainability* of water supply utilities, in particular small-scale utilities.

(4) The fourth component has been named **"Adaptive Management"**. For water supply utilities, change is inevitable - which could be in the form of water availability, water quality, consumer perception, policy formulation etc. However, it is the uncertainty of change that is a major concern for planners. To cope with uncertainty, there is a need for water supply utilities to continuously monitor these changes and arrive at feasible alternatives to counter potential ill effects brought about by the changes. *Adaptive Management* is an approach that seeks to provide flexible and responsive management approaches over time (Gregory et al., 2006). For *Adaptive Management* to succeed there must be an awareness of the problem which can be comprehended from 'requests for information made by consumers', mechanisms and funds for research to address the problem ('development expense ratio') and exchange of scientific ideas and experiences with like-minded partners ('number of international collaborations').

(5) The fifth component **"Private Investment"** in water supply utilities seeks to address the involvement of the private sector in water supply. A toned down form of the 'Public-Private-Partnership (PPP)', *Private Investment* not only serves as an additional source of income for the utilities but also projects a confident and reliable look to the stakeholders. Since private investors invariably look for high rate of returns, this will encourage the water supply utilities to have efficient systems and better management, capable of delivering quality product. This indicator is of particular significance for small-scale utilities in Japan to improve on the debilitated state of existing finances. The amount of private investment made in a franchise can be gauged by monitoring the 'percentage of outstanding revenue bonds' and the 'redemption rate of revenue bonds'. The 'rate of interest of revenue bonds' will serve as an incitement for private investors. The 'net worth to total capital' measures the indigenous equity stake of the water supply utility, and varies inversely with the amount of *Private Investment*, and thus has a negative loading in Table 2.9.

(6) The sixth component is a very important indicator in light of the current situation and has been called **"Green Water Supply"**. In context of climate change, developing a *Green Water Supply* system is an important objective for water supply utilities, especially so in Japan which has committed to reducing the Greenhouse gases (GHG) emissions by 25% in 2020 from the 1990 base year. Although the water sector contributes to less than 1% of the nation's total GHG emissions, reduced 'power and energy consumption', thereby leading to reduced 'GHG emissions', will go a long way in establishing *Green Water Supply* in Japan.

(7) The seventh component evaluates the water quality aspect from the consumer's point of view and has been called **"Consumer Satisfaction for Water Quality"**. The Intergovernmental Panel on Climate Change (IPCC) forecast warmer and wetter days for Japan in the future (Bates et al., 2008). This has a direct repercussion on the water quality in terms of microbial growth, pollutant concentration etc., which could well entail a change in the treatment technology. Although the quality of drinking water in Japan is comparable with the best in the world, complaints due to disinfection by products (Trihalomethanes-THM), Cryptosporidium, chlorinous odor etc. are still rampant (Itoh et al., 2006). Hence as indicated by the PCA results, to ensure *Consumer Satisfaction for Water Quality* in Japan, the 'THM' and 'total organic carbon (TOC) concentrations as ratios of standard levels' will have to be minimum, as indicated by the negative loadings of these variables in Table 2.9, while water relatively 'free of chlorinous and musty odors' enhance the *Consumer Satisfaction for Water Quality*.

(8) The eighth component has been named **"Emergency Response Index"**: As highlighted before, with an expected increase in the variability of precipitation pattern, the occurrences of flood and droughts become more pronounced. Hence, an effective *Emergency Response Index* will be required to ensure safe and equitable distribution of treated water. 'Drinking water storage in event of disaster' and 'emergency water vehicles ratio' are among the important variables contributing to this PI component. Oki and

Musaike (2009) point out that as of 2005, close to 11,000 km of the existing pipelines were installed more than 40 years ago. Hence having a satisfactory ‘pipeline rehabilitation rate’ would improve the efficiency of the supply systems, which could prove very useful in periods of droughts.

(9) The last component of the 9-cPIS is the **“Earthquake Resistant Supply”**: Japan is situated on the Pacific ring of fire, at the juncture of three tectonic plates, where earthquakes are a common phenomenon, hence highlighting the importance of having an “Earthquake Resistant Water Supply Network”. The PCA indicates that ‘distribution reservoir, treatment plant and pump stations seismic facilities rates’ are the more crucial variables affecting this component. Although not relevant from a climate/ socioeconomic change point of view, this component is significant in Japan’s context, reinforcing the notion mentioned earlier that the PI system needs to be site specific.

2.7.4 Regression equations for components

The regression equations for each component are developed using the component scores. Hence the magnitude of each component can be mathematically calculated as

$$\left|PC_i\right|_{i=1to9} = \sum_{1}^{k} CS_k X_k$$

Where

PC = Magnitude of Principal Component

CS = Component Score

X = Magnitude of contributing variable

k = Number of contributing variables

Equations 2.1 through 2.9 describe the regression equations developed for each of the 9 components of the 9-cPIS. The coefficients in the equations correspond to the component scores resulting from the PCA, as indicated previously in Table 2.9

$$EV = (0.264\ EV_1) + (0.241\ EV_2) + (0.253\ EV_3) + (0.152EV_4) \quad (2.1)$$

$$EP = (-0.256\ EP_1) + (0.244\ EP_2) + (0.206\ EP_3) + (0.201\ EP_4) + (-0187\ EP_5) \quad (2.2)$$

$$FS = (0.280\ FS_1) + (0.275\ FS_2) + (0.232\ FS_3) + (0.207\ FS_4) \quad (2.3)$$

$$AM = (0.285\ AM_1) + (0.252\ AM_2) + (0.247\ AM_3) \quad (2.4)$$

$$PIN = (0.341\ PIN_1) + (0.313\ PIN_2) + (-0.232\ PIN_3) + (0.199\ PIN_4) \quad (2.5)$$

$$GWS = (-0.366\ GWS_1) + (-0.319\ GWS_2) + (-0.323\ GWS_3) \quad (2.6)$$

$$CSWQ = (-0.315\ CSWQ_1) + (-0.281\ CSWQ_2) + (0.288\ CSWQ_3) + (0.263\ CSWQ_4) \quad (2.7)$$

$$ERI = (0.335\ ERI_1) + (0.284\ ERI_2) + (0.286\ X\ ERI_3) \quad (2.8)$$

$$ERS = (0.351\ ERS_1) + (0.334\ ERS_2) + (0.271\ ERS_3) \qquad (2.9)$$

where,

EV: Economic Value of Water; EP: Employee Productivity; FS: Financial Sustainability; AM: Adaptive Management; PIN: Private Investment; GWS: Green Water Supply; CSWQ: Consumer Satisfaction for Water Quality; ERI: Emergency Response Index

Note: Refer indicator codes in Table 2.9 for details of variables

2.8 Additional applications of the 9-cPIS

2.8.1 Benchmarking

An important aspect of PIs is that it can be used for benchmarking. The main advantage of benchmarking is that it helps to compare the performance of different water supply utilities, within or across countries, thereby encouraging healthy competition among companies to provide efficient and reliable services, which are financially beneficial. As a result, the indicators used for benchmarking traditionally have a strong emphasis on the financial state of utilities.

Benchmarking with the appropriate indicators is even more crucial in context of Japanese water utilities since as seen previously in Figure 2.4, very few utilities actually participate in the benchmarking exercise. The 9-cPIS is a condensed set of indicators, which is easier to manage and evaluate. Not only does it monitor various aspects of the supply system, it also takes into consideration the current and future areas of concerns for water supply utilities in Japan. The equations 2.1 through 2.9 result in an index for each component whose magnitudes are proposed for benchmarking. Such an index is particularly useful in encouraging the participation of those utilities that are reluctant in divulging details of financial, operational or personnel information, which is usually required in traditional benchmarking. Since only the indices of different utilities would be compared, there is a strong possibility of broader participation. Figure 2.6 demonstrates the application of the 9-cPIS in benchmarking for selected water utilities in Japan.

It is important to note that, for convenience sake, the magnitudes of each of the components have been standardized between the range 0 and 1, so that all components can be represented on the same figure. The typical standardization formula used is described in equation 2.10.

$$\text{Standard Value} = \frac{(\text{Original value} - \text{Minimum value}}{(\text{Maximum value} - \text{Minimum value})} \qquad (2.10)$$

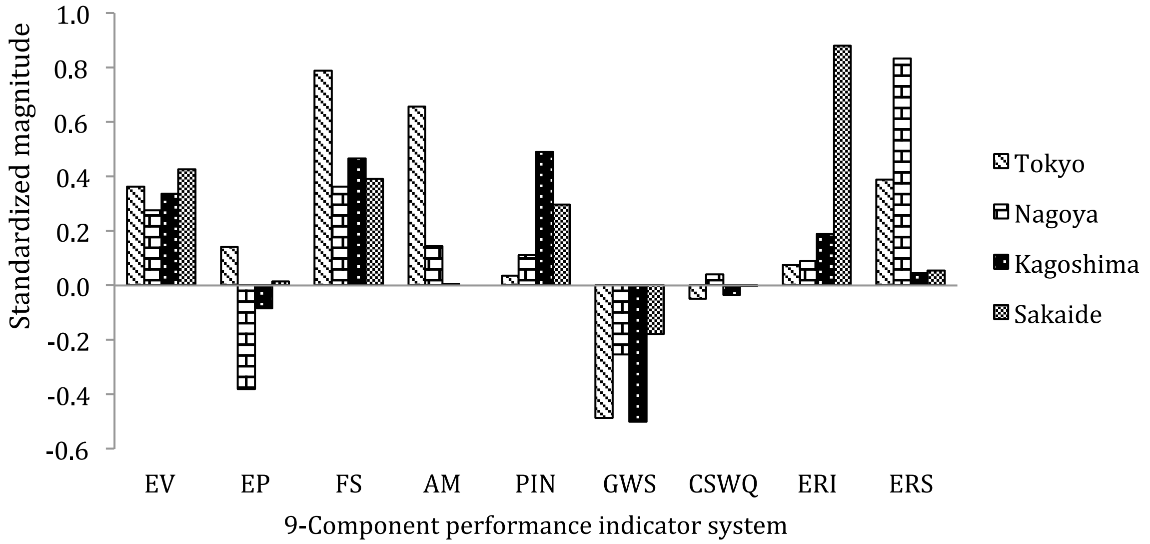


Figure 2.6: Trend of 9-cPIS for selected water utilities in 2007

As observed in Figure 2.6, there are nine indices corresponding to the 9 components of the indicator system, which are compared for four utilities in Japan – Tokyo, Nagoya, Kagoshima and Sakaide. Among these, the Tokyo and Nagoya water utilities are large-scale utilities with service population above 1 million, the Kagoshima utility is a medium sized utility with service population of 579,000, and while the Sakaide utility has a service population of 56,000. It is distinctly seen that the Tokyo water utility overshadows the others in terms of Financial sustainability, Employee productivity and Adaptive Management, suggesting a profitable business. Similarly the Sakaide water utility appears to score highly on the Emergency Response Index. By comparing the indices of the 9-cPIS, water utilities in Japan can gauge their relative positions with respect to other similar utilities, and make efforts to stay competitive, if required.

Apart from benchmarking their performances against other utilities of similar scale of supply, utilities can also monitor the trend of their own performances over the years, and address areas of concerns, if any. Figure 2.7 shows the trend of the 9-cPIS for the Nagoya water utility for the years 2004 through 2007. Accordingly it can be seen that there has been a general improvement in performance with respect to all nine components, over the years, with a pronounced improvement in the Earthquake Resistance Supply component. These observations are very significant because when comparing the performance of Nagoya with other water utilities in Figure 2.6, although the Nagoya water utility compares poorly with the others in the areas of Employee productivity, Financial sustainability and Economic value of water, there has been marked progress over the years, suggesting that the utility is heading in the right direction. Hence, in this case although external benchmarking suggests a problem, internal benchmarking makes the picture clearer.

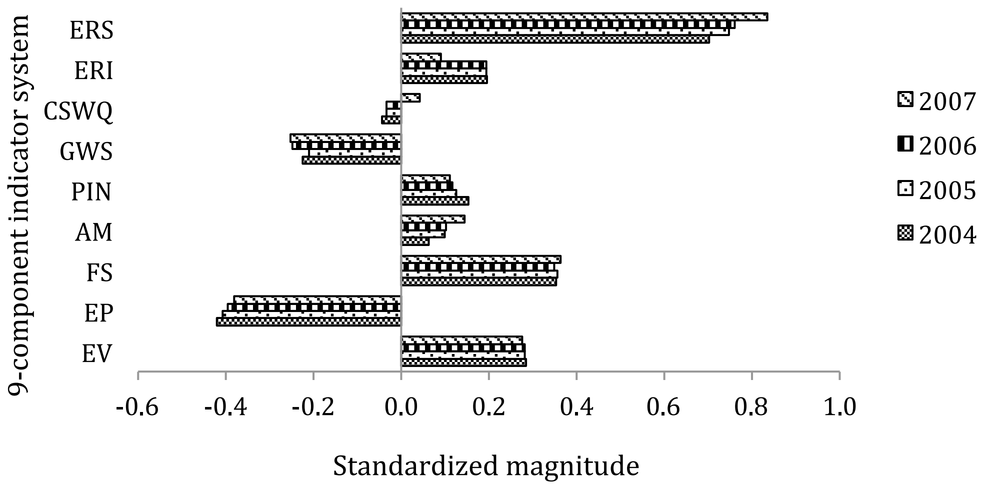


Figure 2.7: Trend of 9-cPIS for Nagoya

As mentioned earlier, the 9-cPIS is a condensed set of only 33 variables, which the water utilities will find easier to evaluate and manage. It was shown earlier in Figure 2.4 that less than 5% of the utilities which took part in the benchmarking exercise in 2007 could provide information for all the 137 original PIs. In contrast, based on the data collected from the JWWA, for the same year, Figure 2.8 shows the number of utilities that have provided data corresponding to the 9 components of the 9-cPIS.

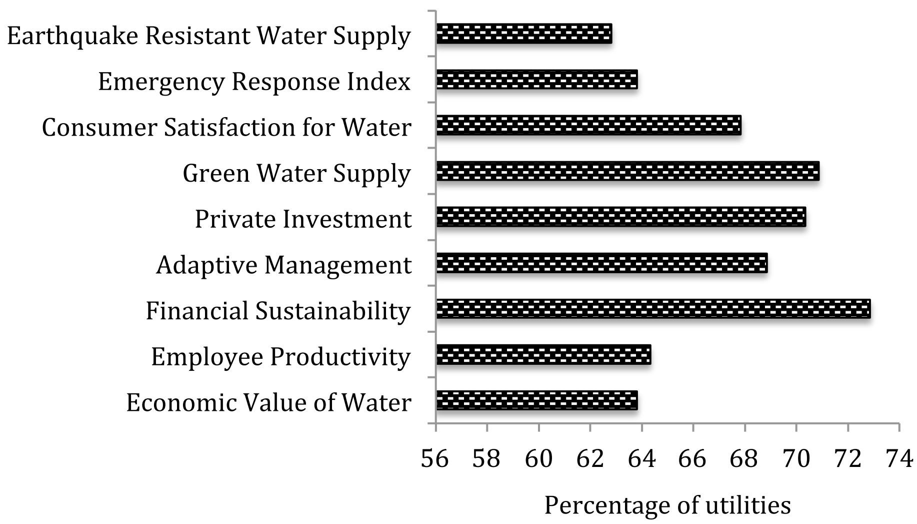


Figure 2.8: Data availability for the components of the 9-cPIS in 2007 (Source: JWWA, 2008)

Accordingly it is seen that more than 63% of the utilities, which took part in the benchmarking exercise in 2007 provided data for all the components of the 9-cPIS. For the Earthquake Resistant Water Supply, data availability was the least, with 63% of the utilities providing the relevant data. For Financial Sustainability, data availability was maximum with 73% of the utilities providing the relevant data. It can be thus seen that, there is more data available for the 9-cPIS components compared to the original 137 indicators, suggesting that the use of the 9-cPIS in benchmarking will be more effective and useful.

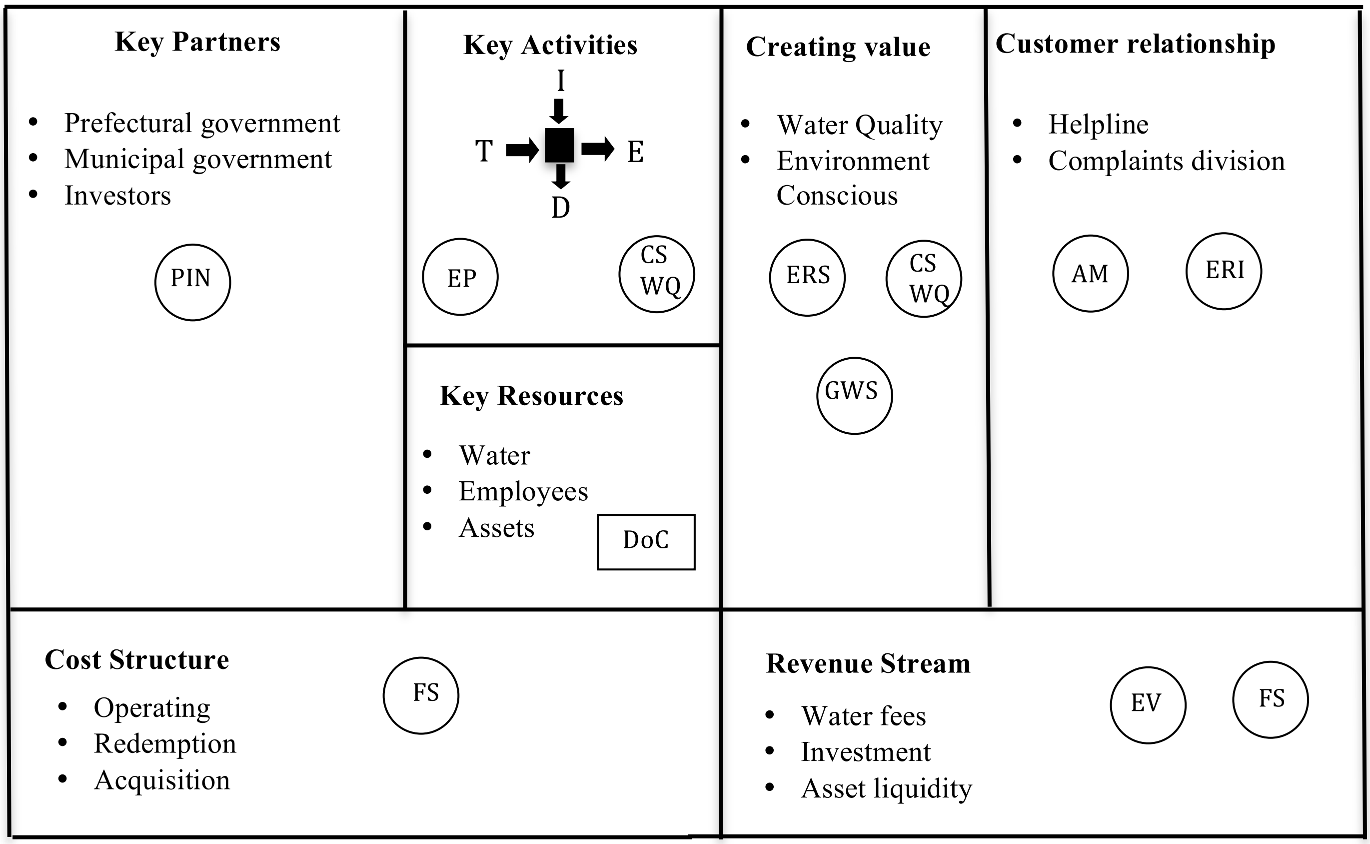
2.8.2 Evaluating business models

There is no generally accepted definition of a business model. Shafer et al. (2005) performed an exhaustive literature review on the definitions of business models and arrived at four common components of business models as defined by various researchers – strategic choices, creating value, capturing value and the value network. A business model for water supply would be slightly different from a regular business model because water supply is not a purely financial business but entails a social element as well, especially in context of the Japanese water supply, which is under government control. Hence, apart from ensuring financial security, water utilities in Japan have to address social obligations too. Figure 2.9 shows a prospective business model canvas proposed for Japanese water supply utilities. The aim of this section is not to develop a new business model but rather show the application of the 9-cPIS in evaluating the model. Hence, the model proposed for this study uses the basic framework developed by Osterwalder and Pigneur (2010). The study has tried to adapt this model for water supply utilities. The various elements of the model, and the application of the 9-cPIS in evaluating each element are described hereafter.

The business model canvass entails 8 elements. The ‘key partners’ element refers to the stakeholders involved in the water supply business. Since over 95% of the water utilities in Japan are under the public sector, prefectural governments are the major partners. Private investors and members of the community are the other partners. The *Private Investment* component of the 9-cPIS can evaluate this aspect of the business model.

The ‘key activities’ for a typical water supply utility in Japan includes intake, treatment, distribution and effluent. The intake and distribution activities are mainly concerned with the quantity of water available for supply. Since the current penetration rate is above 97%, water shortage is presently not a concern (JWWA, 2008). Given the nature of Japan’s supply system and decreasing population trend, it is unlikely that water shortage will be a problem in the future. Hence the more pertinent indicators with respect to this element of the business model can be limited to *Consumer Satisfaction for Water Quality* and *Employee Productivity*.

For any water supply utility, water, employees and assets form the core of the ‘key resources’. In light of changing climate and socioeconomic conditions, these resources are likely to be the Drivers of Change, which would affect water supply systems and the subsequent management of water supply. *The Employee Productivity* and *Financial Sustainability* components address this element of the business model.



I – Intake, T – Treatment, D – Distribution, E-Effluent, DoC – Drivers of Change

EV: Economic Value of Water; EP: Employee Productivity; FS: Financial Sustainability

AM: Adaptive Management; PIN: Private Investment; GWS: Green Water Supply

CSWQ: Consumer Satisfaction for Water Quality; ERI: Emergency Response Index

ERS: Earthquake Resistant Supply

Figure 2.9: Evaluating business models of Japanese water supply utilities with 9-cPIS

The 'value proposition' element of the business model refers to the appeal of the product and its special characteristics. Reliable supply of good quality water and an environmentally friendly supply system add to the appeal of produced water. The *Green Water Supply* and *Consumer Satisfaction for Water Quality* components can evaluate the value proposition component of the business model. Further, having a sound *Earthquake Resistant Supply* will enhance the reputation of the water supply utility and garner more trust from consumers.

The 'customer relationship' element is the interaction of the customers with the water supply utilities. These interactions could be in the form of meetings, questionnaires, forums etc. However, in this context the customer relationship that directly leads to problem solving has been considered as customer relationship. This can be gauged by the *Adaptive Management* component, which takes into account customer-utility interaction to dynamically solve problems. The 'cost structure' and 'revenue streams' elements form the financial array of the business model. While operation, redemption and acquisition contribute to the expenses, water fees, asset liquidity and investment make up the revenue. The *Financial Sustainability* and *Economic Value* components of the 9-cPIS are capable of evaluating these elements of the business model.

It is thus apparent that the 9-cPIS is diverse enough in nature, and capable of monitoring different aspects and activities of a typical business model for water supply.

2.8.3 Operating the PDCA cycle for planning and management

The 9-cPIS developed in this study is a condensed set of 33 variables, which is easier for water supply utilities to monitor, and subsequently use for planning and managing the supply. This section endeavors to explain the potential application of the 9-cPIS in the PDCA (Plan-Do-Check-Act) cycle, developed by Deming (1986), for water supply utilities in Japan.

The PDCA cycle is an iterative, four-step problem solving/planning process used in business process improvement. The components of the PDCA cycle are

- **Plan:** To plan for improvement, first there needs to be an awareness of the problem. A thorough awareness of the problem is essential to develop a proper understanding of how the system will behave under the anticipated problem. The 'Plan' stage of the cycle seeks to investigate not only the problem, but also possible solutions to the problem. There are a number of methods used in this stage, notable among these are – customer/supplier mapping, pareto analysis, solution/fault tree, evaluation matrix, flow charting, cause and effect diagram etc. Based on the understanding of how the problem impacts the system, potential solutions are drawn up for possible evaluation, which are then tested in the next stage of the cycle.

- **Do:** The potential solutions developed in the 'Plan' stage are then tested in real time scenarios. Depending upon the complexity of the system and severity of the problem, the solutions are tested at different scales. Ideally, the solution should be tested on a small-scale basis to ensure that the experiment does not affect the entire line of operations. In some cases, especially where the system is quite complex, simulation models can be used to test the potential solutions. Thus, the aim of the 'Do' stage is to discover how the system responds to the possible solutions.

- **Check:** This stage involves gauging the effect of the possible solutions against a set of indicators. The choice of indicators is particularly important. The indicators will need to evaluate the performance of the system in context of the problems that the system faces. Moreover, the indicators should encompass the areas of future concerns to ensure proper management of the system. If the possible solutions perform well on the set of established standards, then the solution can be implemented on a larger scale. If not, further modifications should be made to the proposed solutions to achieve the required targets.

- **Act:** This is the final stage of the cycle where the feasible solutions, which perform well against the performance indicators, are implemented. It must be noted that the PDCA cycle is iterative and the process does not end with the 'Act' stage. Rather, new potential problems are identified over a period of time and corrective measures suggested, making it a dynamic solution cycle.

The 9-cPIS is primarily concerned with the 'Check' stage of the PDCA cycle, and addresses the current and future concerns that water supply utilities in Japan are likely to face. The *Emergency Response Index* indicator evaluates the ability of the system to cope with expected changes in water quantity (floods and draughts). *Consumer Satisfaction for Water Quality* evaluates the quality of supplied water in terms of consumer satisfaction (effects of increased turbidity, pollutant concentration, microbial growth etc.) while the *Adaptive Management* indicator throws light on the ability of the utility to dynamically cope up with concerns (Research and Development). *Green Water Supply* monitors the environmentally friendly aspect of the system (GHG emissions, energy consumption etc.). *Financial Sustainability, Economic Value of Water* and *Private Investment* monitor the financial aspects of the utilities. The *Employee Productivity* and *Private Investment* indicators monitor the effect of decreasing service population.

Figure 2.10 explains the potential application of the 9-cPIS in the PDCA cycle. Accordingly, the cycle can be implemented in two broad stages – planning and implementation. In the planning stage, after identifying current and potential concerns, target objectives and feasible solutions are explored (Plan). Further, scenario models are developed which integrate the drivers of change along with the operational features of the supply system (Do). The 9-cPIS is, then, used to evaluate the scenario models (Check). Based on how the models perform against the indicator system, modifications and revamping of the supply system is proposed and project approval procured (Act). In the implementation stage, after arranging for the necessary finances, infrastructure and personnel (Plan), the feasible solutions are implemented in real time situations on, preferably, a small scale basis (Do). The system is then monitored against the 9-cPIS to check how well the modeled solutions perform in real time (Check). Depending on the system response, against the indicator system, further fine-tuning of the system is explored (Act).

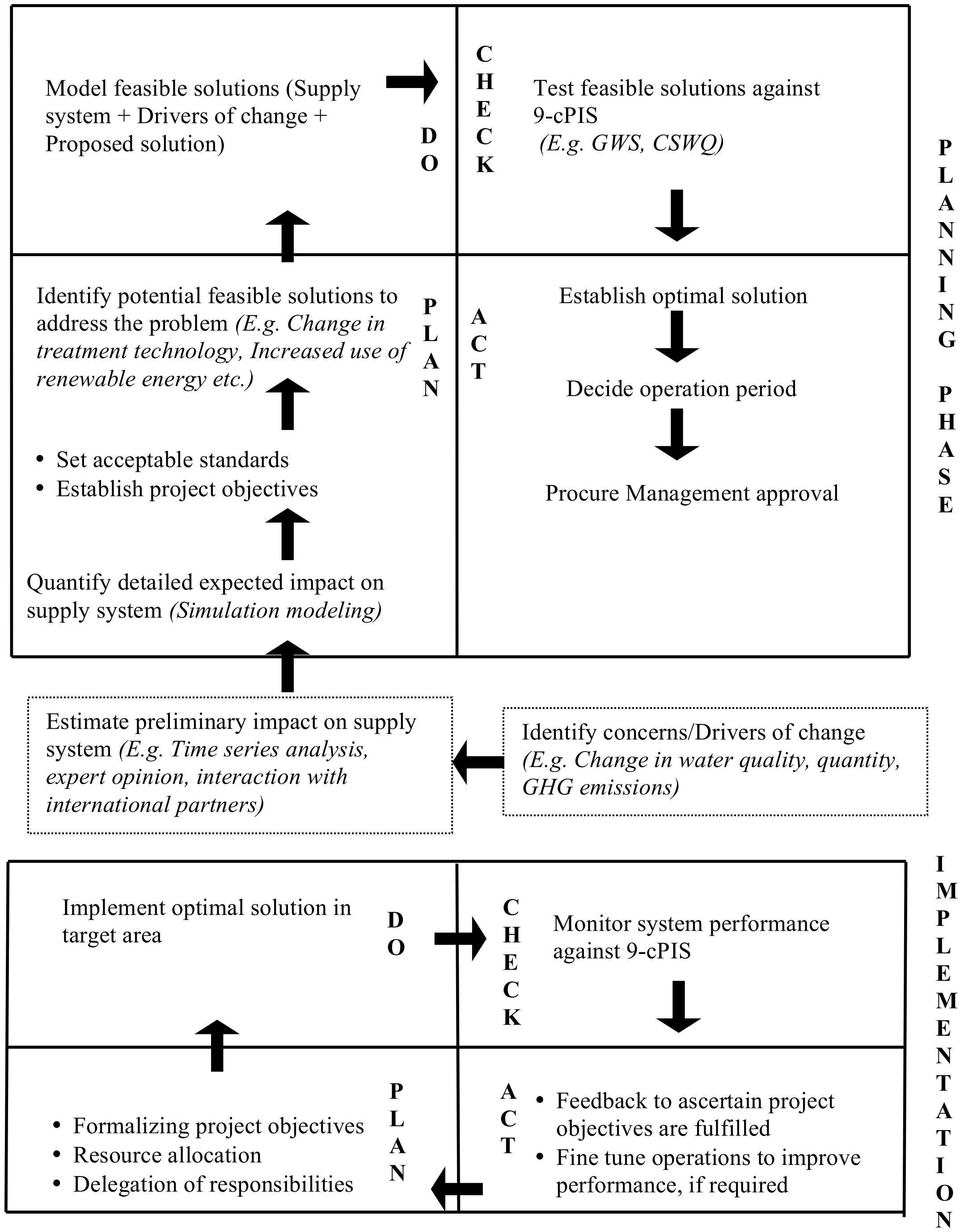


Figure 2.10: Application of the 9-cPIS in PDCA cycle

2.8.4 Benefit for small water utilities

97.5% of the water utilities in Japan serve less than 50,000 customers, and are called small water utilities. The original 137 PIs are too many in number for small utilities to adopt because of resource and financial constraints. This section endeavors to show the cost-effectiveness of the 9-cPIS so that even small water utilities can use it. Out of the 9 components, the measurement of only the variables of the *Consumer Satisfaction of Water Quality* component requires specialized equipment and technology, to measure the concentrations of THMs, TOC, residual chlorine, Geosmin and 2-MIB in finished water. However, all these items are already included in the Japanese Water Standards via the revised Water Supply Act of 2003, which makes it mandatory for utilities to make this information available to the public at all times. Currently, only the larger utilities have the facilities and equipment to test the various parameters of drinking water. The small water utilities collect water samples and send them to the Water Quality Monitoring Centers of the nearest large utility, for a stipulated fee. Hence, the small water utilities will not incur any additional cost on account of this component of the 9-cPIS. For the remaining components of the 9-cPIS, collecting the information pertaining to the corresponding PIs merely involves good bookkeeping and maintaining records of operation activities, which is not financially taxing

2.9 Summary

The objective of this thematic study was to develop a practical and relevant PI system to evaluate water supply utilities in Japan for various scenarios of climate change. PCA was employed to identify the pertinent PIs, derived from an existing set, to help gauge the performance of water supply systems to be modeled for future scenarios. The results of the analysis suggest that out of 138 PIs, only 9 components consisting of 33 variables (9-cPIS) are relevant in evaluating the performance of potential water supply systems. The components comprise of *Economic Value of Water, Employee Productivity, Financial Sustainability, Adaptive Management, Private Investment, Green Water Supply, Consumer Satisfaction for Water Quality, Emergency Response Index* and *Earthquake Resistant Water Supply*.

The findings of this study propose a set of key PIs that are easier and more convenient to manage, especially for small-scale utilities, while at the same time address the current and future concerns that the water supply utilities in Japan can expect. Further, the use of the 9-cPIS will make subsequent modeling studies with different scenarios of climate conditions less onerous, without compromising the reliability of interpreted results. It must be mentioned that the key PIs developed in this study are not an exhaustive list but are primarily meant for modeling studies, which is data driven. Hence, some relevant variables for which data is currently not available or which are likely to impact water supply systems in future could not be included in the study.

Additionally, the study presents the potential application of the 9-cPIS in evaluating business models, and the PDCA cycle for water utilities in Japan. By providing the utilities with a reduced set of relevant indicators, the study can make a significant contribution in the planning and management of the water supply. By developing scenarios of anticipated changes in water availability and quality, and observing the effect on the aforementioned components, water supply utilities can make informed and rational decisions to ensure the sustainable supply of safe and good quality water in Japan.

CHAPTER III

INTRODUCING "PUBLIC INTEREST" IN WATER SUPPLY

3.1 Background

Developing PIs in the water industry is usually considered a technical endeavor, which has been traditionally carried out by experts, academicians and practitioners with very little to no involvement of the consumers. Most PI systems developed worldwide are utility-centered, meant to gauge the performance of different aspects of the supply system in an effort to foster improvement. The 9-cPIS developed in the previous chapter is no different. Each component of the 9-cPIS focuses on monitoring and evaluating the performance of the various facets of the water supply utilities in Japan. However, in the recent past there has been an increasing emphasis on involving consumers in water supply decisions. Water companies are now confronted with the challenge to make the shift from just being a water supplier towards becoming a customer-oriented service provider with a high sustainability profile and a "license to deliver" (Hegger et al., 2011). Meeting consumer expectations, and accounting for it in utility management plans, is now becoming a norm rather than the exception. With progress in technology and ease in obtaining information, consumers are becoming more knowledgeable, and have begun to take a keen interest in the water supply systems. Advances in medical science has now brought to fore the presence of various carcinogenic compounds present in water, which were hitherto undetected. With improved knowledge about these compounds and their effects, consumer expectations of water quality are becoming more demanding, especially in developed countries.

The need to understand consumer expectations becomes even more pronounced in light of climate change, where water supply utilities will have to take crucial decisions to address the demands of multiple users.

An understanding of the consumer expectations from water supply will essentially require interaction with the consumers in the form of interviews, questionnaires, forums, or can be indirectly gauged from the nature and number of customer complaints. The understanding of expectations increases with broader public participation. Literature is abundant with case studies of consumer participation or involvement in water supply, but has been generally confined to the following areas

- **Customer satisfaction**

A number of studies have been carried out to evaluate the consumer satisfaction in relation to water quality, taste, service etc. The usual method for gathering this vital piece of information is by disseminating questionnaires, and then using statistical techniques to quantify the consumer satisfaction. Perceptions about consumer satisfaction for drinking water quality may vary across countries. In a study conducted in Taiwan (Lou et al., 2007), it was found that the consumer satisfaction was primarily governed by absence of unpleasant odors, whereas in UK and Portugal (Doria et al., 2009) and Canada (Turgeon et al., 2004; Levallois et al., 1999), the estimation of water quality was mostly influenced by satisfaction with organoleptic properties (especially flavor). Doria (2010) comprehensively identifies the factors influencing public perception of drinking water quality. According to him, although the perception of water quality results from a complex interaction of diverse factors, the sensorial information (organoleptics) has the greatest influence. Among the other factors are: risk perception, attitude of the public towards the chemicals used in water treatment, contextual cues provided by the supply system, familiarity with specific water properties, trust in suppliers, past problems attributed to water quality and information provided by the mass media and interpersonal sources. Apart from water quality, consumer satisfaction is also affected by water supply service, where continuity of water supply is the major concern. Water supply utilities in many Asian cities like Delhi, Karachi, UlanBator, Vientienne, Gaza strip etc. are good examples that fail to deliver consumer satisfaction for continuity of service (ADB, 2004; Al-Ghuriaz and Enshassi, 2005).

- **Willingness to pay (WTP)**

A popular area of consumer participation is in evaluating the public's Willingness to Pay for water and water related services. The literature, mostly centered on developing countries like South Africa (Goldblatt, 1999), China (Wang et al., 2010), Zambia (Ntengwe, 2004), Nigeria (Whittington et al., 1991), Palestine (Al-Ghuriaz and Enshassi, 2005) etc. indicate that consumers are likely to pay more for improved water supply services (increased reliability) than any other water related service. A notable exception is a case study in India (Raje et al., 2002) where it was found that satisfaction level of the consumer does not affect the WTP, affordability to pay does. The magnitude of WTP varies according to geographical and social profiles. Studies reveal that while consumers in Mexico (Vasquez et al., 2009) indicate their WTP as much as 78% (median value) more than the current water prices, in China (Wang et al., 2010) the WTP is low at 12% more than the present water prices.

- **Consumer acceptance of recycled water**

Because of increasing water scarcity, population explosion leading to increased water demand, and changing climate regimes, many water utilities and countries have been encouraging the usage of recycled and reused water. Recycled water is mainly being used for non-consumptive purposes and consumer involvement has been emphasized on gauging the acceptance of recycled water. The various studies carried out emphasize that acceptance of recycled water is governed by awareness of the need for recycling, perceptions of recycled water and knowledge of the recycling process (Dolnicar et al., 2011).

Acknowledging and accepting the fact that the water demand cannot be met in any other way, and public interest towards environmental protection also increases the acceptance level of consumers towards recycled water (Menegaki et al., 2007). Although generally there is widespread acceptance of recycled water, concerns about the quality of recycled water are still present (Higgins et al., 2002).

- **Water regulation**

Perhaps the most popular example of public involvement in water services regulation is the 'WaterVoice' (customer service committees) in the UK established by the Ofwat (Water services regulation authority of UK) to ensure that the interests of the customers and potential customers are effectively represented (Franceys and Gerlach, 2011). Zambia has a number of Water Watch Groups (WWGs), which serve as a formal link between the regulators and customers and provide valuable feedback on services delivered by the regulated companies.

Apart from the aforementioned fields, studies on consumer involvement have also been noted in understanding consumer behavior towards conservation, household water use, hygiene and risk perception (Hurlimann et al., 2011; Peter, 2010; Jorgensen et al., 2009; Itoh et al., 2006 etc.), and rural development (Nare et al., 2011; Prokopy et al., 2005 etc.)

All the studies citied above have tried to address the consumers' point of view. This study goes beyond just that. Apart from evaluating the **"public's interest"** (P_{INT}) in water supply, which is from a consumers' point of view, this study attempts to relate this to the 9-cPIs which has been developed from the utility's point of view. Hence, an effort has been made to elucidate the nexus between the two points of view.

3.2 Rationale of the study

"Public Interest in the context of this study is defined as those aspects of the water supply system in which the consumers are naturally interested, and place high importance."

Since the PIs usually cover the entire range of water supply operations and services, understanding the public's interest will highlight those PIs, which are important for the consumers. Hence, consumer expectations can be identified, which has three distinct benefits.

(a) By understanding the areas of the supply in which the public is interested, the utilities can highlight and present to the consumers their achievements and efforts in those areas. This will help them establish a good relationship with the consumers, thereby earning their support, which will be very useful when adaptation measures for climate change are to be implemented.

(b) By knowing consumer expectations, water utilities will be able to market their product in a better way, catering to consumer interest. For example, if consumers indicate their interest in the 'Green Water Supply' PI, utilities can focus on the environmentally friendly aspect of their product while presenting it to consumers. This will, hopefully, wean away the consumers from other environmentally unfriendly sources such as bottled water.

(c) Having knowledge of consumer expectations will help the utilities to identify certain PIs that are sensitive to consumer choice. This knowledge becomes particularly useful for decision-making in testing times when various tradeoffs may have to be considered. For example, if consumers prioritize the 'Water Quality' PI over the 'Water Price' PI, in scenarios of degraded raw water quality this would provide a sound rationale to the utilities for increasing water prices, within reason, to maintain adequate quality. Utility managers may consider changing the type of water treatment, with a reasonable increase in water price, in order to maintain the quality the consumers require.

3.3 Thematic objectives and scope of study

The thematic objectives of this study are

- To evaluate and quantify Public Interest (P_{INT}) in water supply

A questionnaire survey with randomly selected consumers was performed to evaluate and further quantify P_{INT}. The questionnaires were only disseminated in the Kansai region of Japan, to limit the geographical boundaries of the study, and achieve greater control.

- To develop a relationship between the P_{INT} and each component of the 9-cPIS.

Selected water utilities were evaluated for P_{INT}. The nine components of the 9-cPIS were estimated for each of the selected utilities, which were used to establish a mathematical relationship with the P_{INT} in order to understand the relationship between the consumers' and utility's points of view. This relationship was further used in the study to develop a tradeoff between meeting consumer expectations of water quality and reducing energy use.

3.4 Research Methodology

3.4.1 Schematic of activities

Figures 3.1 presents the schematic of the sequence of activities and events carried out to evaluate and quantify the P_{INT}, while Figure 3.2 depicts the flowchart for establishing the relationship between the P_{INT} and each component of the 9-cPIS.

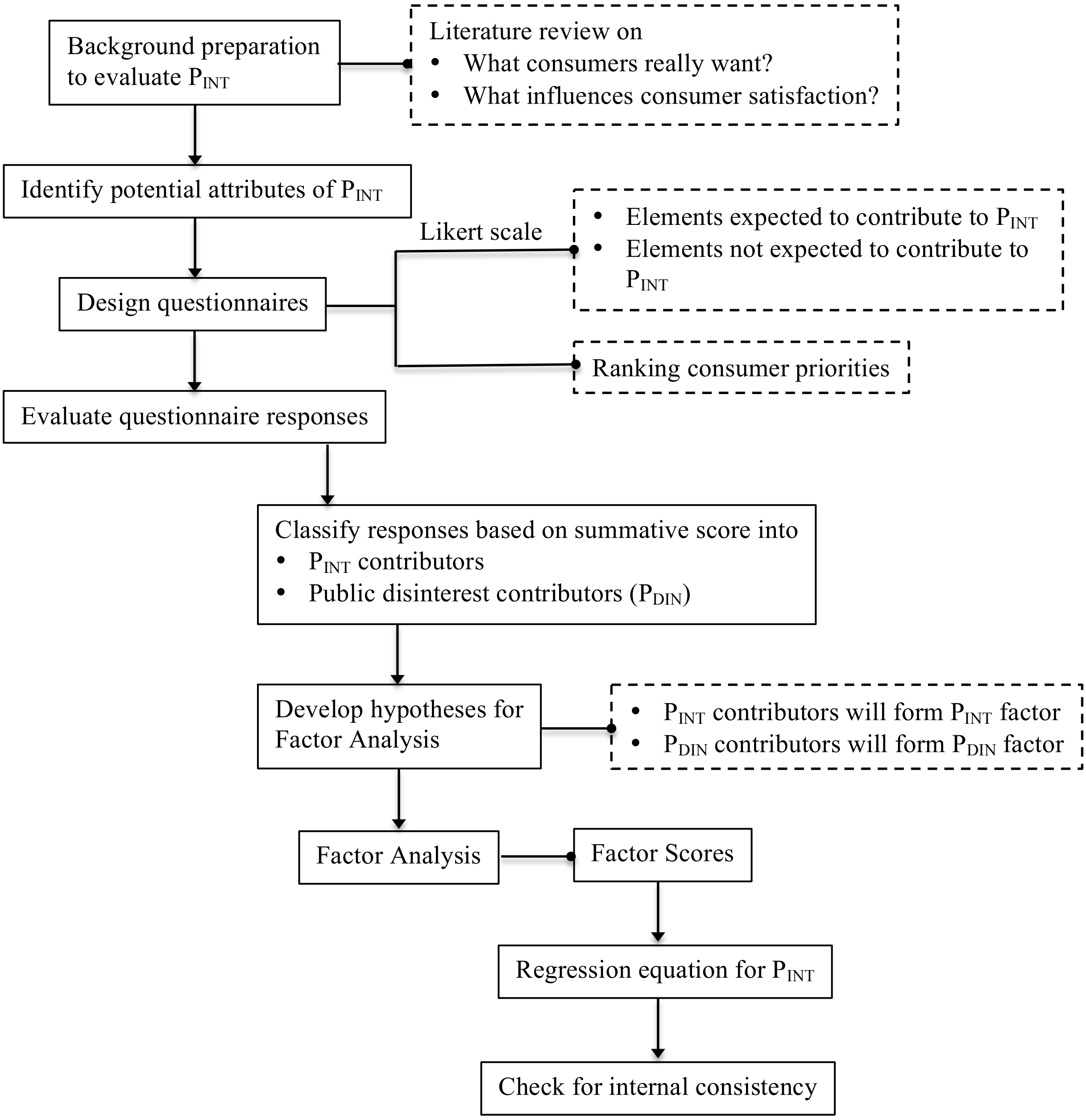


Figure 3.1: Schematic for quantifying Public Interest (P_{INT})

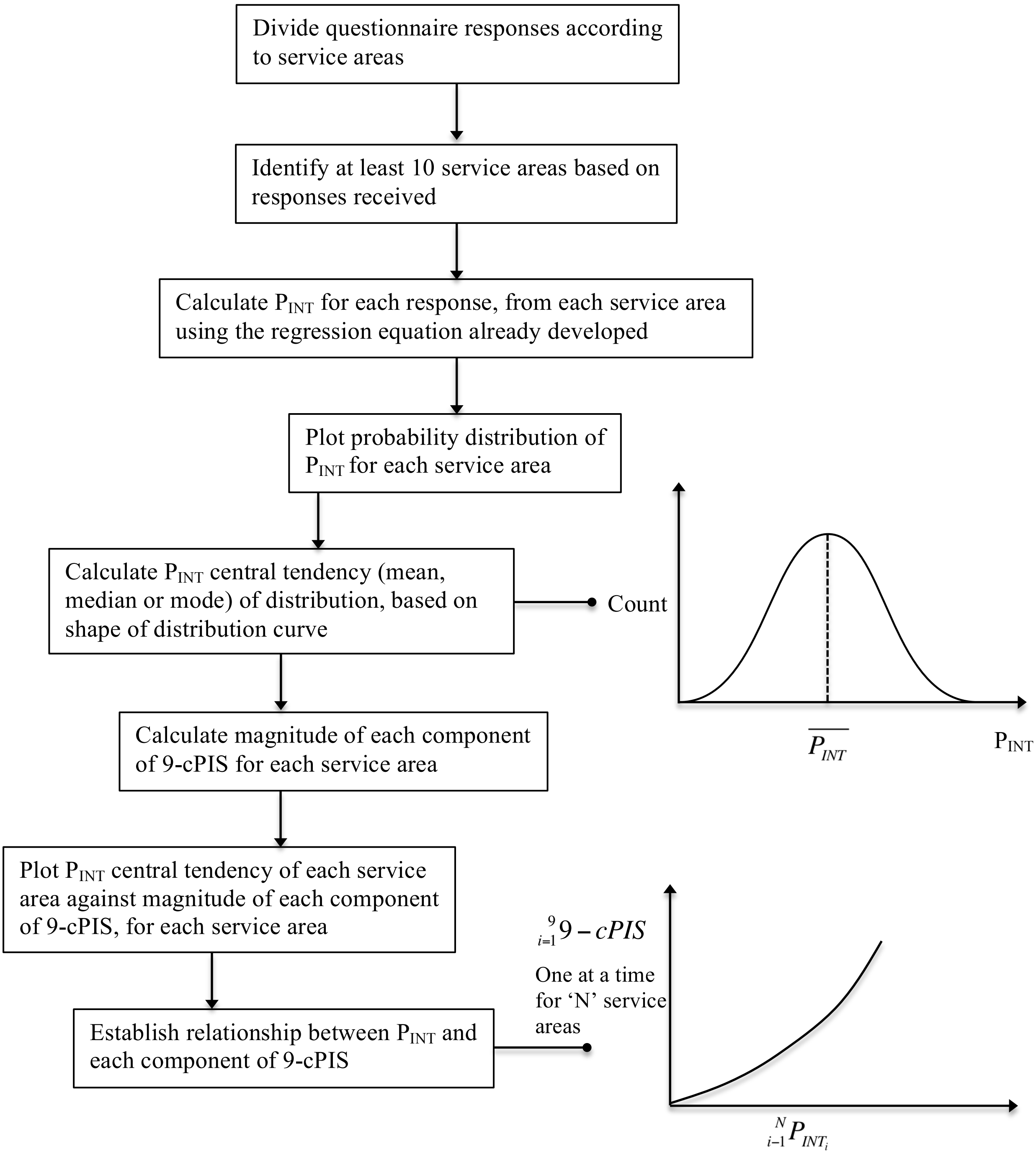


Figure 3.2: Schematic for establishing relationship between Public Interest (P_{INT}) and 9-cPIS

3.4.2 Background preparation to evaluate P_{INT}

Understanding the nature of P_{INT} requires an insight into what consumers really want or expect from their water utilities. There are certain aspects of the supply system, which have a direct repercussion on consumer interest and concerns. These aspects will, in all likelihood, vary from place to place. Consumers in developing countries may aspire for reliability and continuity of service from their providers, whereas in developed countries the focus may be on the quality aspect of water. Further, consumer expectations may also vary across cultures, age, professions and social status — the affluent educated individuals may like to see their utilities more environmentally friendly, the older consumers may be more concerned with water prices, for women with children the water quality may assume top priority etc. This section seeks to identify, from various case studies in literature, consumer needs and wants, which will be helpful in designing the questionnaires for this study.

A common concern for consumers, in developing and developed countries alike, is reliability of service (e.g. Zerah, 2000; Koss and Khwaja, 2001). Howe et al. (1994) point out that while out of pocket losses appear small, water customers place high value on reliability. A survey conducted by Mori Consulting (2002) in UK ranked reliable and continuous service as the most highly rated service aspect, followed by water pressure and appearance. Apart from reliability, in the same survey, respondents indicated their willingness to pay more for improved safety, taste and smell. A number of other studies also point out that taste, odor and smell of water are top priorities for consumers (Lou at al., 2007; Doria et al., 2009; Turgeon et al., 2004; Levallois et al., 1999 etc.). It can, thus, be ascertained that good water quality figures high on consumer expectations.

Having a reasonable price structure is another aspect that is given high importance by consumers. Raje et al., (2002), in a study carried out in India, reported that in the economically challenged group even though consumers were aware that improved water services would lead to significant benefits, there was absolutely no Willingness to Pay more because the consumers simply could not afford increased costs. Similar findings were reported by Wang et al. (2010) in China, where it was found that as the income level of consumers increased, the WTP more for improved services also increased. However, the poorest consumers refused to accept any price hike.

Drinking water is essentially the most basic and crucial service. Consumers place their trust in the utilities to provide them with safe drinking water, which is a huge responsibility for the utilities. This is particularly significant with respect to the presence of harmful elements in the water that cannot be detected by smell, taste or odor. In a questionnaire study carried out in Japan, Itoh et al. (2006) reported that people judge tap water as harmless and reduce their concern on its quality when their trust in the waterworks system increases. Hence, trust in water supply utilities is another aspect of the water supply system, which is crucial from a consumer's point of view.

As society becomes more progressive, consumers expect more transparency and access to information regarding the supply system. In a study conducted in Japan, Hirayama (2004) showed that information that increases controllability about the risk of drinking water quality can reduce citizens' concern in that respect. Providing the information consumers want is a part of the customer services operations, which makes customer service an important aspect contributing to P_{INT}.

Based on the information above, although difficult to generalize, it is apparent that water quality, reliability of service, trust in water utilities, price of water are among the areas that are important from the consumer's point of view.

3.4.3 Questionnaire design

3.4.3.1 Contents of questionnaire

An Internet based questionnaire survey was carried out in the Kansai region of Japan to evaluate the P_{INT}. The first section of the questionnaire contained questions pertaining to socio demographic attributes – gender, age, household income and geographic location.

Eight questions (items) were included in the questionnaire to evaluate and quantify P_{INT} in the second section of the questionnaire. Each of the eight items was chosen on the basis of two criteria. First, their inclusion should be supported by literature and past studies. Second, each item should be related to the 9-cPIS, so that an empirical relationship between the P_{INT} and 9-cPIS could be established. Based on the literature review in section 3.4.2, four potential items were identified which were thought to influence P_{INT} – Water quality, Price of water, Customer service and Trust in water utilities. A notable exception here is reliability of service. This was not considered in the design because Japan has an efficient supply system, with over 97% of the population receiving continuous water supply (JWWA, 2008). The contents of the questionnaire survey also included four aspects that were thought not very important from the viewpoint of consumers – Employee productivity in utilities, Financial state of utilities, Research and Development in utilities and Equity of distribution. None of these items figured in any literature or previous studies on consumer wants or customer satisfaction, suggesting that they are exclusively utility-centered, and thus were thought to collectively influence the 'Public Disinterest (P_{DIN})' trait. The inclusion of these aspects was to facilitate the extraction of two distinct factors — P_{INT} and P_{DIN} — from the Factor Analysis carried out subsequently. Each of the eight items of the questionnaire and the traits that they are expected to measure are presented in Table 3.1

Table 3.1: Questionnaire items used in the survey

Questionnaire item	Expected contributors to
Water quality	Public Interest
Price of water	
Customer service	
Trust in water utilities	
Employee productivity in utilities	Public Disinterest
Financial state of utilities	
Research and Development	
Equity of distribution	

A copy of a sample questionnaire, both in English and Japanese, used in the study can be found in Appendix B.

3.4.3.2 Measurement scale of responses

A five point Likert scale was used to evaluate the responses received for the second section of the questionnaire. The Likert scale is the most widely used scale to measure people's attitudes, preferences, opinions, conceptions etc. in general (Wu, 2007; Gob et al., 2007 etc.). Likert (1932) developed the principle of measuring attitudes by asking people to respond to a series of statements about a topic, in terms of the extent to which they agreed, thereby tapping into the cognitive and affective components of attitudes. An added advantage of the scale is that it provides the respondents with the option "Undecided" or "Don't know". This ensures that the respondents are not forced into making a choice when they are unsure about a certain item, thus providing additional reliability to the results.

In this study, respondents were given a range of choices to indicate how important to them were the questionnaire items listed in Table 3.1. The range of choices and corresponding scores are presented in Table 3.2

Table 3.2: Likert scale range and scores used in the study

Degree of agreement	Score
Very Important	5
Important	4
Undecided	3
Slightly Important	2
Not important	1

3.4.3.3 Dissemination area and sample size

The Kansai region of Japan was selected as the study area, where questionnaires were disseminated to stratified, randomly selected subjects. Kansai region was selected for logistics – It is closer to the author’s laboratory, and it is more convenient to connect with water utilities in the region. The Kansai region is made up of six prefectures – Osaka, Kyoto, Nara, Hyogo, Wakayama and Shiga. Of these, Osaka is the largest, both in area and population, while Wakayama is the smallest. Figure 3.3 depicts the geographic location of the Kansai region with Japan, with the constituent prefectures. It was endeavored to have equal number of male and female respondents to investigate the P_{INT} in the gender context.

Having an adequate sample size is essential for results to be statistically significant. A sample is a subset of cases selected from a population. Small sample sizes have a greater margin of error, casting doubts on the credibility of results. With an increase in the sample size the reliability initially increases very steeply, but as the sample size grows there are diminishing returns in terms of reliability from any further increases in sample size (Wangcharoen et al., 2005). The sample size calculations for experimental designs take into consideration the population size, acceptable sampling error and desired confidence level. Generally, a confidence level of 95%, with sampling errors ranging from 3% to 5% is considered for sample size determination.

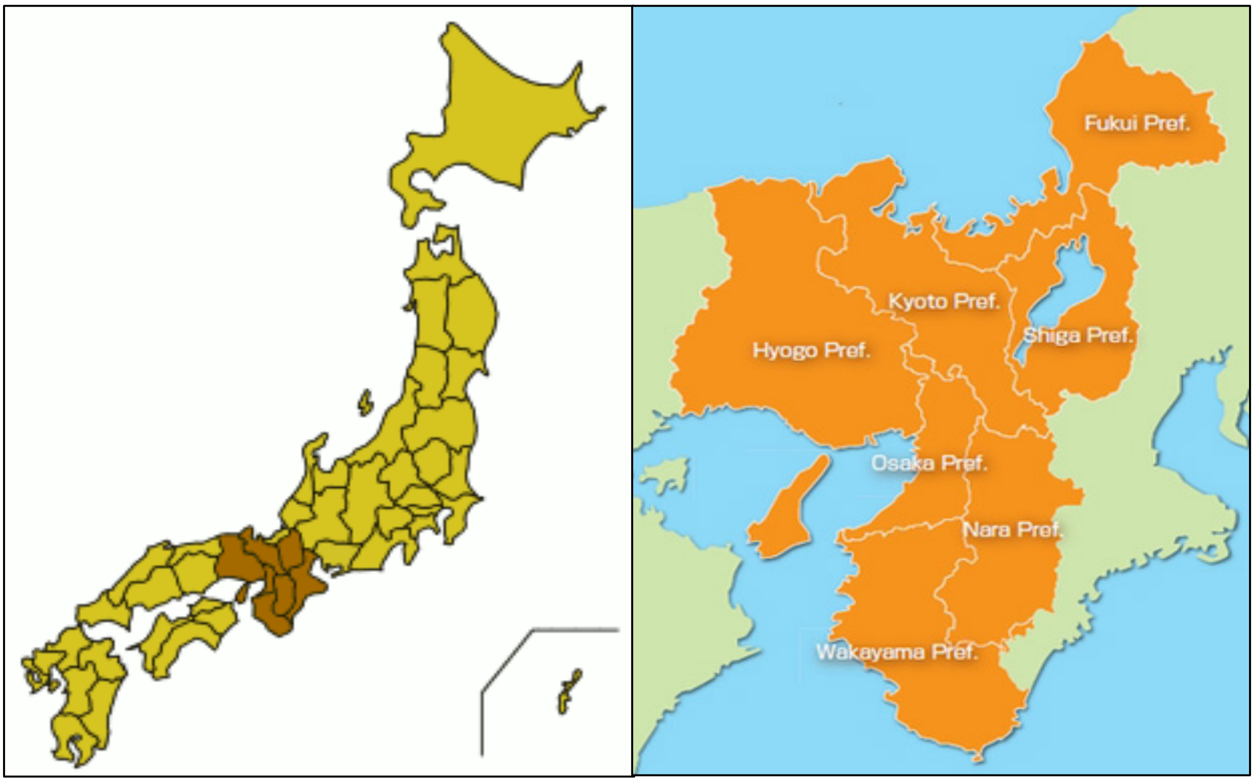


Figure 3.3: Geographic location of the Kansai region within Japan and its constituent prefectures

Apart from targeting a confidence level of 95% with acceptable sampling error of 3%, a governing factor to determine the sample size for this study was with respect to the requirements of Factor Analysis, because the results of the questionnaire would be further used in Factor Analysis. Given that there are eight questions in the questionnaire, and considering a case to variable ratio of 10 as recommended by Bryant and Yarnold (1995), a minimum sample size of 80 is required for each service area. Further, since it was proposed to divide the questionnaire responses into at least ten service areas so that a relation between the P_{INT} and 9-sPIS could be developed, the total minimum size amounted to 800. To be safe, a sample size of 1500 was thus targeted.

3.4.3.4 Mode of dissemination

A web based questionnaire survey was used for this study. Market researchers have long recognized the advantages of Internet-based surveys, the most important of these being lower costs and faster response time (e.g., Ilieva et al., 2002; Duetskens et al., 2004 etc.). Unlike traditional forms of surveys, it is easier to have access to a unique population through web-based surveys (Wright, 2005). Further, data can be collected continuously, regardless of time of day and day of week, and without geographical limitation (Madge, 2006). In spite of the numerous advantages of web-based surveys, there are some drawbacks associated with it.

Currently the biggest concern with Internet based surveys is coverage bias, arising due to sampled people not having Internet or choosing not to access the Internet (Alvarez and VanBeselaere, 2005; Wright 2005 etc.). Despite expediential growth of the Internet there are still large numbers of people who do not have access and/or choose not to use the Internet.

However, as of the end of 2010, there were 94.62 million Internet users in Japan, accounting for approximately 79% of the population (Statistic Bureau, 2011). Additionally as seen in Figure 3.4, the rate of Internet use has been on the rise from 34% in 2000 to over 90% in 2008. Although data for the year 2011, in which this study was conducted, is not available, it can be speculated that the rate of Internet use must have increased. Given the development in telecommunications in Japan over the last few years, and people's dependence on the Internet for various purposes, it is highly unlikely that the Internet use has gone down.

Further, as observed in Figure 3.5, the rate of Internet use appears more or less the same across genders, indicating no bias in this regard. Expectedly, the younger generation exhibits a greater predilection towards Internet related activities, compared to the older citizens. Hence, it appears that coverage bias does not seem to be a limiting factor in this study.

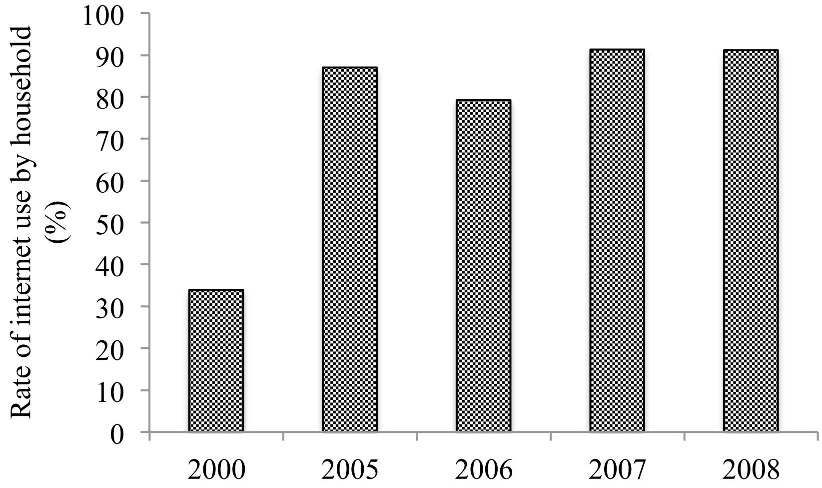


Figure 3.4: Trend of Internet use in Japanese households
(Data Source: Global ICT Strategy Bureau, Ministry of Internal Affairs and Communications)

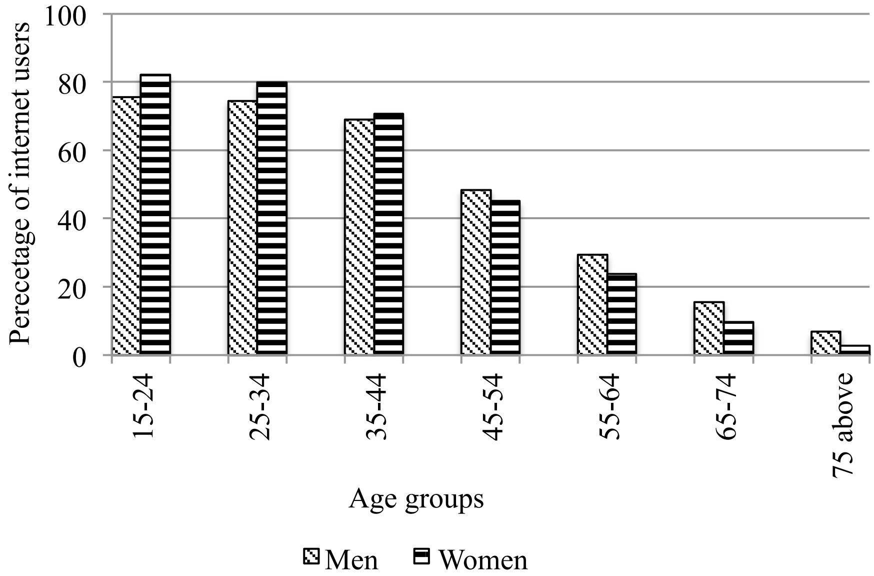


Figure 3.5: Trend of Internet use in Japanese households based on gender in 2006
(Data Source: Global ICT Strategy Bureau, Ministry of Internal Affairs and Communications)

Studies also point out to the fact that it is difficult to ascertain the response rate and response origins with web based questionnaires (Wright, 2005). The response rate was not a very significant aspect in this study since a minimum sample size was established. The analysis was performed only after the required responses were received. To address the concerns regarding response origins, respondents were asked to mention their geographic locations in the first section of the questionnaire, as mentioned previously in Section 3.4.3.1. Another widespread concern with Internet based surveys is that users may treat the survey as spam if not presented properly. To ensure that the questionnaire was not mistaken as spam and treated with respect, an official foreword, endorsed by the university at which the author is, was placed before the first section of the questionnaire.

The questionnaire survey for this study was conducted using the services of Macromill Inc., a Tokyo based leading online research company in Japan. All questions were translated into Japanese, since that is the primary mode of communication, both written and verbal, in Japan. The survey was conducted between December 26, 2011 and Dec 28, 2011. First, requests were sent to approximately ten thousand subjects (10,000) on December 26 to inquire of their availability for the survey. After that, the responses were segregated based on geographic location and gender because the survey required an equal number of male and female respondents from the Kansai region only. The full questionnaires were then sent to these selected respondents.

3.4.4 Factor Analysis (FA)

Factor Analysis (FA) was performed to quantify P_{INT}. FA is a statistical technique that seeks to account for patterns of collinearity among multiple metric variables. The basic assumption in FA is that if variables are correlated to each other, it is because they are measuring the same "trait". FA is very similar to PCA, and both will lead to similar substantive conclusions. The main difference between these types of analyses lies in the way the communalities are used. In PCA it is assumed that the communalities are initially 1. In other words, PCA assumes that the total variance of the variables can be accounted for by means of its components (or factors), and hence that there is no error variance. On the other hand, FA assumes error variance. This is reflected in the fact that in FA the communalities have to be estimated, which makes FA more complicated than PCA, but also more conservative (Byrant and Arnold, 1995).

The terminology used in FA is very similar to that used in PCA, with exactly the same steps being performed in both cases. Detailed information about the terms and definitions can be revisited in Section 2.4.2.

3.4.5 Check for internal consistency

The consistency of the results obtained from FA was tested with the commonly used index – Cronbach's Alpha. The purpose of performing this check is to verify whether or not the variables contributing to a factor have a close relation. Cronbach's alpha is test of reliability, which measures how closely related the variables contributing to a factor are (Cronbach, 1951). Cronbach's alpha takes a value between 0 and 1, and high values are used as evidence that the items measure an underlying (or latent) construct.

Cronbach's alpha can be conceptually represented by equation 3.1

$$\alpha = \frac{N.\bar{c}}{\bar{v}+(N-1).\bar{c}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where

N = Number of items/variables contributing to the factor

$\bar{c}$ = Average inter-variable covariance

$\bar{v}$ = Average variance

George and Mallery (2003) provide the following rules of thumb:

“ > 0.9 – Excellent, > 0.8 – Good, > 0.7 – Acceptable, >0.6 – Questionable, > 0.5 – Poor, and < .5 – Unacceptable”

3.5 Results and Discussion

1648 responses were received during the period December 26, 2011 and December 28, 2011. It must be pointed out that these are the responses after the segregation phase. The segregation of responses were done to fulfill two criteria. First, to ensure that there were equal number of male and female respondents. Second, the respondents were limited to the Kansai region of Japan, made up of the Osaka, Kyoto, Nara, Hyogo, Wakayama and Shiga.

3.5.1 Response classification

3.5.1.1 According to gender

Males – 50%

Females – 50 %

3.5.1.2 According to Prefectures

Figure 3.6 describes the response classification according to the prefectures in the Kansai region of Japan. Out of 1648, the maximum responses (775) were received from the Osaka prefecture, accounting for 47% of the total responses. This is understandable because the population in the Osaka prefecture is the largest among all the prefectures located in the Kansai region of Japan. Also, the maximum questionnaires were sent out to respondents in the Osaka prefecture. 26 and 12% responses were received from the Hyogo and Kyoto prefectures respectively. The least responses were received from Wakayama prefectures, which made up only 3% of the total responses. Responses from Nara and Shiga, each 6% of the total responses, made up the remaining portion of responses.

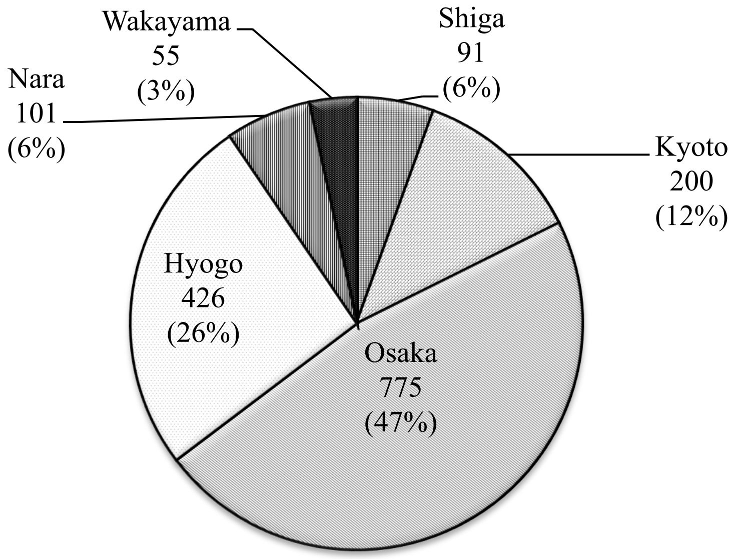


Figure 3.6: Response classification of questionnaire survey according to prefectures

3.5.1.3 According to age groups

Figure 3.7 depicts the responses received from the questionnaires based on different age groups.

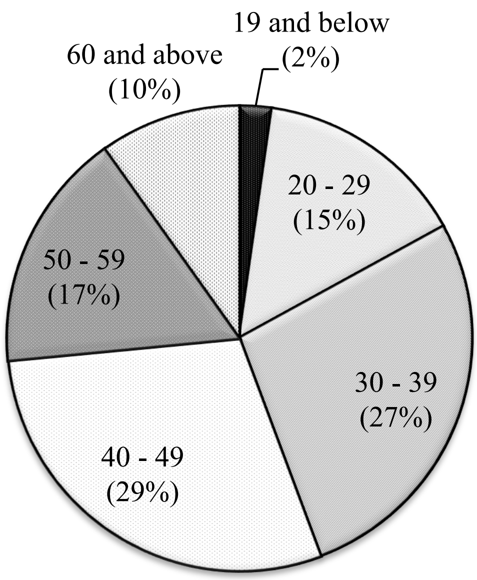


Figure 3.7 Response classification of questionnaire survey according to age groups

The maximum responses were received from the group whose age varied from 40 to 49 years, followed by the group with ages in the range 30 to 39 years. These two groups contributed towards more than half (56%) of the responses, indicating the activeness of middle-aged respondents in the survey.

The younger respondents (age group: 19 and below, and between 20 and 29) formed a mere 15% of the total responses, indicating the lack of interest of youngsters in aspects pertaining to water supply. This is particularly significant since as presented out earlier in Figure 3.5, over 80% of the population in these groups have access to the Internet. This suggests that although the maximum number of questionnaire requests was sent to this group, minimum responses were received from them. Conversely, the combined response rate of senior citizens (age group 50-59, and 60 and above) was higher at 27%, in spite of this group having limited access to the Internet (less than 50%, as seen in Figure 3.5).

3.5.1.4 According to marital status

A large proportion of the respondents were married, accounting for 61.8% of the respondents. Further, out of the 1648 respondents, there was an almost even segregation of respondents with and without children. 863 respondents, accounting for 52.4% of the sample size had children compared to 785 respondents who did not.

3.5.1.5 According to annual household income

Figure 3.8 presents the classification of responses on the basis of household income of the respondents.

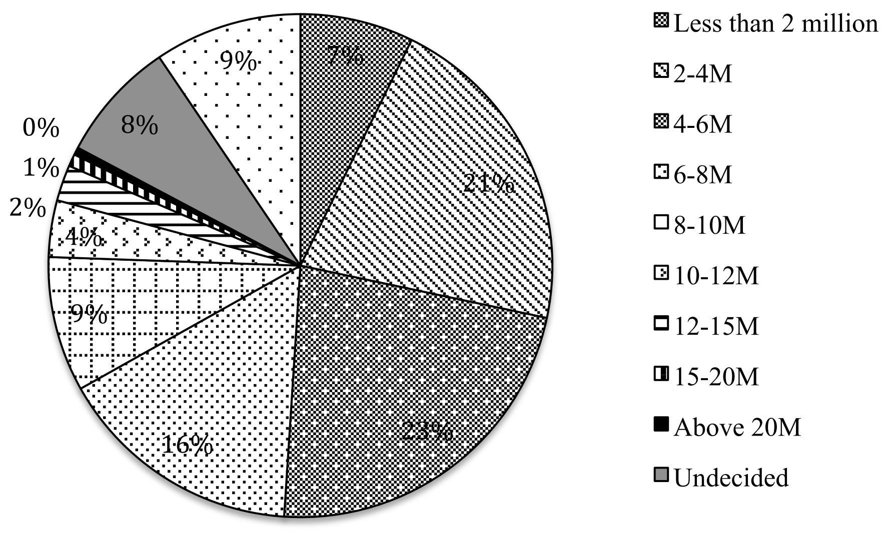


Figure 3.8: Response classification of questionnaire survey according to annual household income

It can be seen that the largest group (23% of the respondents) have an annual household income between 4 and 6 Million Yen, followed by the group with an annual household income between 2 and 4 Million yen (21% of the respondents). 7% of the respondents reported an annual household income less than 2 Million, while only 8 respondents (0.005% of the total respondents, indicated by the black sector in Fig 3.8) reported annual household incomes greater than 20 Million. Generally, there were fewer responses from households with more annual income as compared to households with less annual income. It is apparent from Figure 3.8 that more than two thirds of the respondents reported an annual household income of less than 8 Million yen. Approximately 9% of the respondents chose to withhold their household income, while 8% of the respondents indicated that they did not know their household income. Hence, a significant number (17%) of the respondents did not provide any information pertaining to their household income, suggesting that disclosing information about income may be a sensitive issue with respondents.

3.5.1.6 According to profession

Figure 3.9 presents the questionnaire responses classified with respect to common professions in Japan. Accordingly, housewives or househusbands form a bulk of the responders, accounting for almost 19% of the total responses.

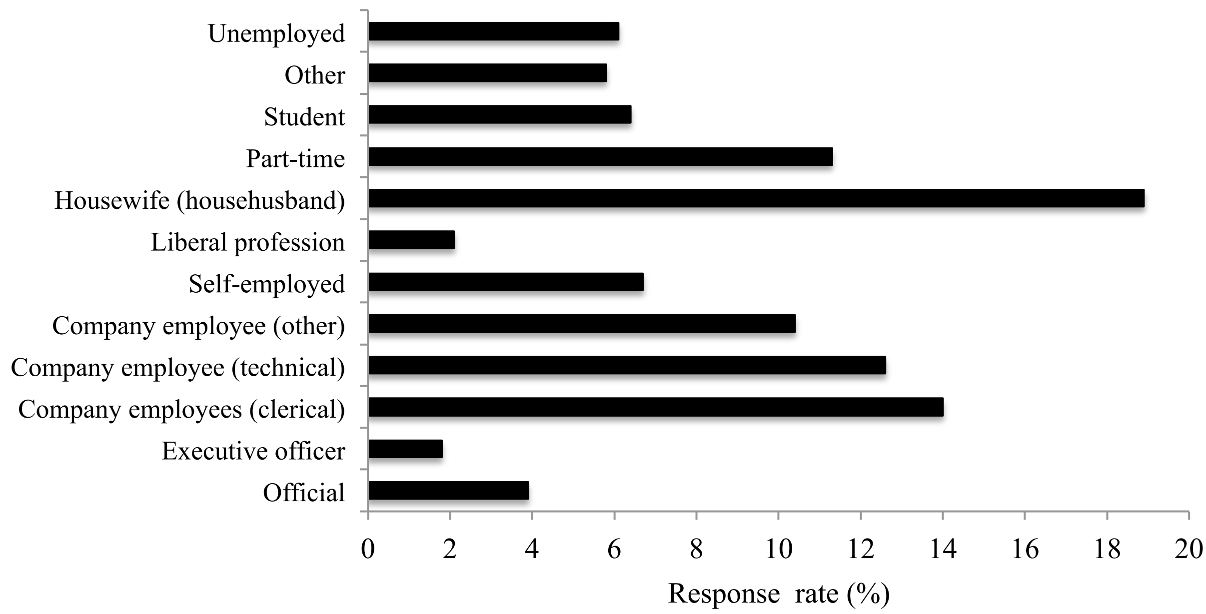


Figure 3.9: Response classification of questionnaire according to profession

Clerical company employees, technical company employees and part-timers form the next largest groups in order or magnitude, with 14, 12.6 and 11.3% contribution to the total response rate, respectively. There was very little participation from individuals with managerial positions like executive officers and officials, with less than 5% responses received from these groups. It would be incorrect to say that a particular group is less interested in the water supply aspects based on number of responses received because there is no data to show how many people from each group have been approached for the questionnaire.

3.5.2 Question-wise analysis of responses

3.5.2.1 Based on total responses

As explained earlier in section 3.4.3.1, the questionnaire contained two parts. The first part requested responders to provide personal and demographic details, while the second part was designed to evaluate the $\mathbf{P_{INT}}$. Question-wise analysis of the eight (8) questions of the second part of the questionnaire has been performed in the current section.

Figure 3.10 presents the range of consumer responses of each of the eight questions. Among the variables, ‘good quality tap water’ appears to be the most crucial variable for consumers. 95.63% of the respondents have indicated that ‘good quality tap water’ is either very important or important to them. Among the other variables, consumers have placed high importance on ‘trust in water supplier’, ‘price of water’ and ‘equity of distribution’. Although the response trend for these three variables is quite similar, ‘trust in water supplier’ scores highly on the ‘very important’ category among the five choices, suggesting that it is perhaps one of the most crucial variable in the eyes of the public.

Contrarily, the ‘financial state of utilities’ and ‘employee productivity in utilities’ seem to elicit very little importance from the consumers – only 18.02 and 19.24% of the respondents respectively find these two variables very important. A key feature to note is that 38.17% and 40.05% respondents respectively have indicated an undecided stance when specifying the importance of these two variables. This suggests that either the consumers do not know the significance of these two variables or they are uncertain whether or not these variables are really important. Under the circumstances, in both cases, it is quite clear that these variables do not garner much importance from the consumers.

Surprisingly ‘customer service’ appears to figure low on importance, with only 20.21 % of the consumers placing high importance on it. A possible explanation for this anomaly could be that in Japan it is difficult to find examples of bad customer service. Japanese people are renowned to be very cordial and polite, and they carry this trait to their places of work. Hence, consumers may have never had an experience of bad customer service, which would make it difficult for them to ascertain whether or not ‘good customer service’ is important. Further, 28.09% of the respondents took an ‘undecided’ stance regarding ‘customer service’, giving further justification to the line of thought that consumers may not be aware of what bad customer service is.

There seems to be a mixed response to the ‘research and development in utilities’ variable with over 66% of the respondents indicating it to be either ‘very important’ or ‘important’, but almost 29% taking an ‘undecided’ stance.

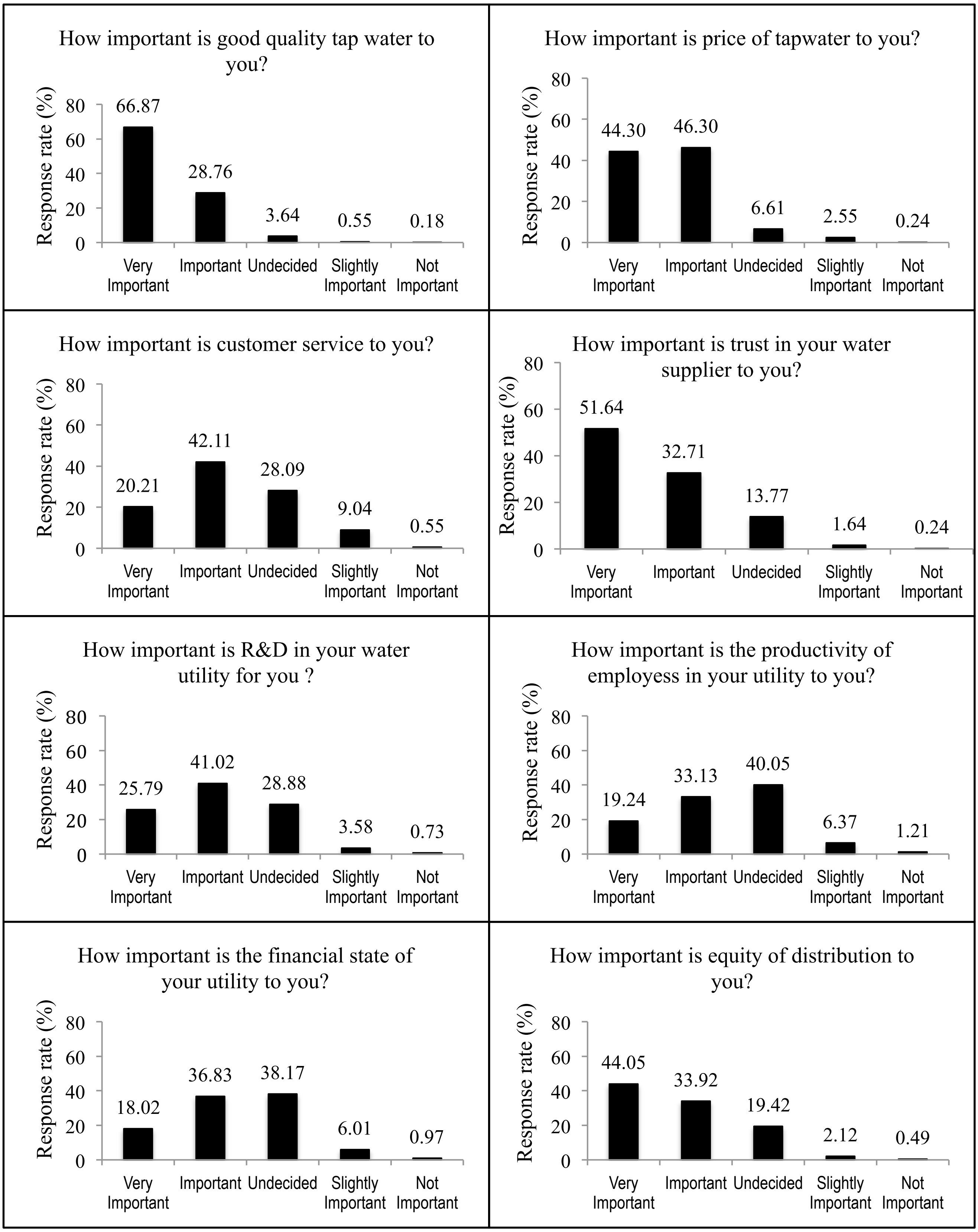


Figure 3:10: Response pattern for questions to evaluate Public Interest

Figure 3.11 presents the summative score of each question (variable) based on the scoring pattern outlined in section 3.4.3.2. The trend is very similar to that when the questions were analyzed individually. Accordingly, respondents have given the highest score to 'good quality tap water', followed by 'trust in water supplier', 'price of water' and 'equity of distribution'. Hence, these four variables appear to be more important for consumers. Conversely, consumers have placed relatively lower importance on 'employee productivity in utilities', 'financial state of utilities', 'customer service' and 'research and development in utilities', suggesting that these variables may not have an significant role to play when estimating the Public Interest.

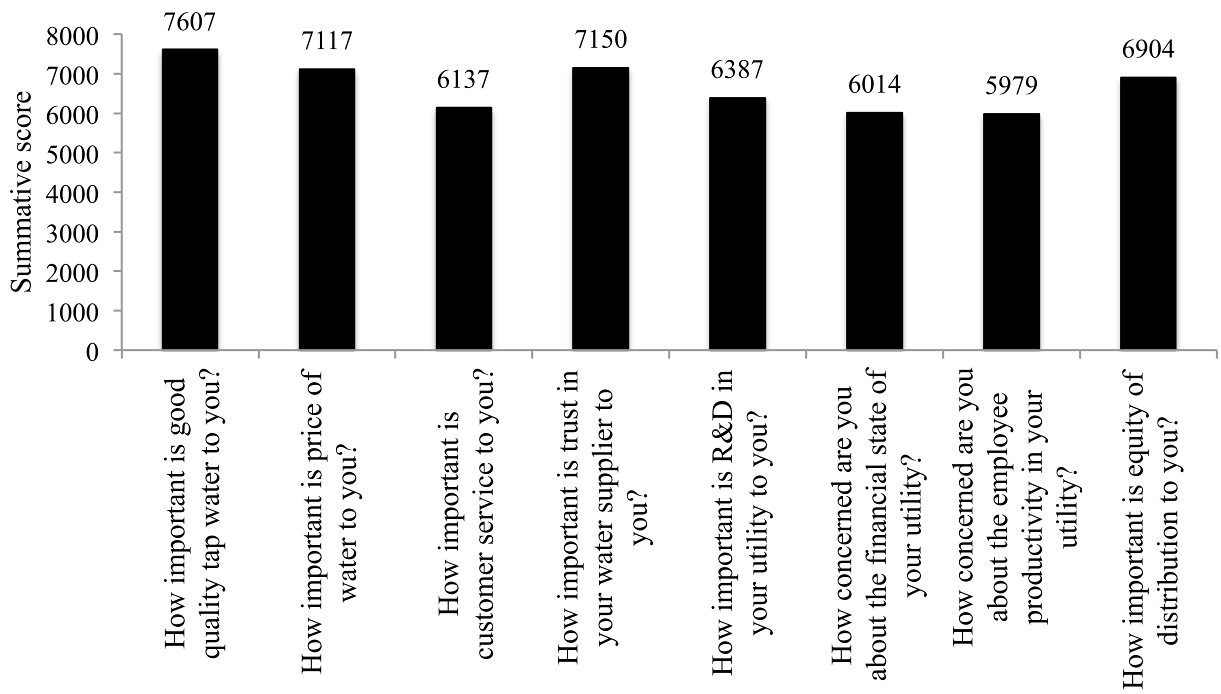
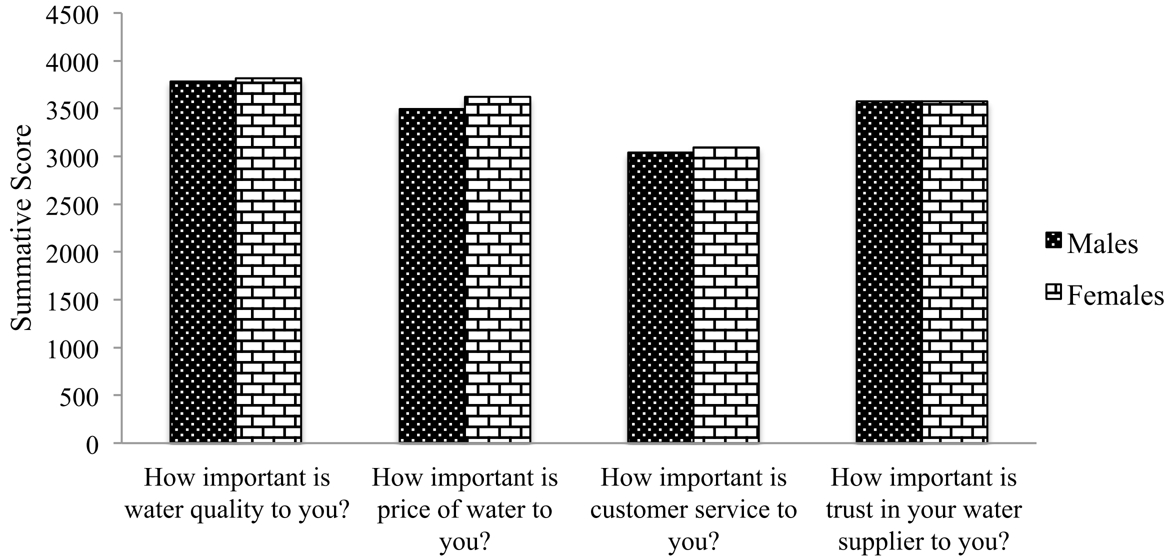


Figure 3.11: Summative scores for total responses, for questions to evaluate Public Interest

3.5.2.2 Based on gender

Figure 3.12 presents gender-wise classification of the summative scores for each of the eight questions for evaluating the Public Interest. It is apparent that the response pattern and trend for each question is more or less similar for both males and females. This suggests that there is virtually no difference in opinions and choices of the consumers based on gender. Further the trend is in good agreement with the overall trend where 'good quality tap water' and 'trust in water supplier' figure high on the importance levels, and 'employee productivity in utilities' and 'financial state of utilities' are deemed less important by consumers.



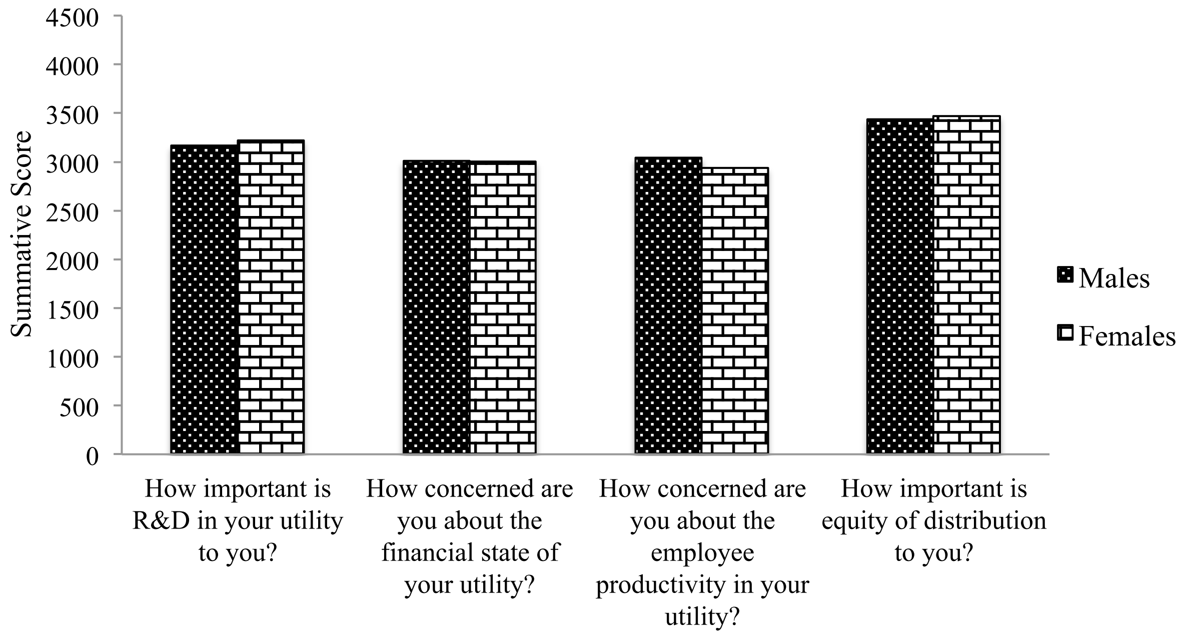


Figure 3.12: Summative scores for questions to evaluate Public interest, based on gender

3.5.2.3 Based on age groups

The summative scores of each age group for the questions to evaluate Public Interest are pictorially represented in Figure 3.13. The average summative score was used to perform the analysis because the number of respondents in each age group was different. Hence, the average summative score was used as a standardization medium. As observed in Figure 3.13, generally there is an increase in the summative scores with an increase in the magnitude of the age groups.

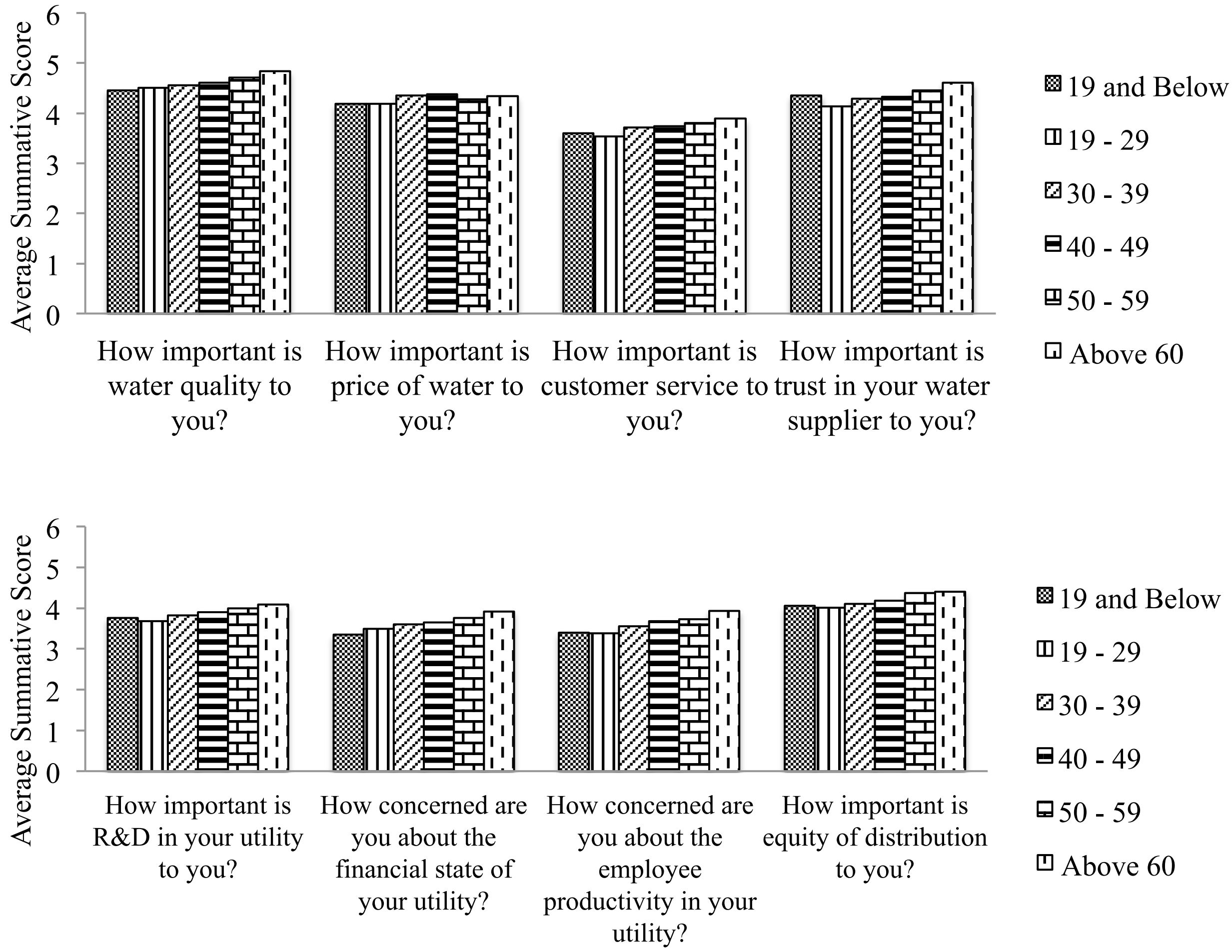


Figure 3.13: Summative scores for questions to evaluate Public interest, based on age groups

The average summative scores calculated for older respondents are visibly higher than those for younger respondents. Given that the summative scores are significantly impacted by the 'very important' and 'important' choices, because these have the highest magnitudes, it appears that the older respondents give more importance to the various aspects of the supply system. This can be attributed to

- Past Experiences: Older respondents are more likely to have had problems with the water supply over the years, especially when the supply system was not as advanced as it is today. This could be a likely cause of concern for older respondents, thereby justifying their interest in the various aspects of the supply system. In light of the current technology and state of the art systems, the younger respondents will have had fewer unpleasant experiences.

- Knowledge: Older respondents are likely to have gathered more knowledge about the water supply system, because of which they place more importance on the diverse properties of the supply system.

- Priorities: Younger respondents may have different priorities. They may be more concerned with other things essential for their personal development instead of the water supply system which is already in a good state.

3.5.3 Factor Analysis Results

3.5.3.1 Hypothesis development

In accordance with the methodology outlined in sections 3.4.4 and 3.4.5, Factor Analysis was performed with responses received for the questions (variables) in the second part of the questionnaire. Although the consumer priorities and general areas of interest have been identified in the preceding section, there is still no mechanism to mathematically cluster the variables of $\mathbf{P_{INT}}$. Hence, the main purpose of carrying out the Factor Analysis was to quantify the $\mathbf{P_{INT}}$ by developing regression equations. An essential component of Factor Analysis is proposing a hypothesis, which would be then tested through the analysis. Based on the question-wise analysis of responses, covered earlier in section 3.5.2.1, the following hypotheses were proposed

- HYP-1: Factor Analysis will lead to the isolation of a factor, which will be called the **"Public Interest ($\mathbf{P_{INT}}$) factor**". 'Good quality tap water' and 'Trust in water supplier' are the primary variables affecting P_{INT}. 'Price of water' and 'Customer service' are among the other variables that have some influence on the P_{INT}.

- HYP-2: The remaining variables (questions) in the study — 'Employee productivity in utilities', 'Financial state of utilities', 'Customer service' and 'Research and development in utilities' — will load on another factor, "**Public Disinterest ($\mathbf{P_{DIN}}$)**" which is the antithesis of P_{INT}.

3.5.3.2 Tests for sampling adequacy

Table 3.3 presents the results of the Kaiser-Meyer-Olkin (KMO) test and the Bartlett's test of sphericity. Details of the two tests can be revisited in section 2.4.2. The KMO index of 0.850 is meritorious, suggesting that the sample size for Factor Analysis is satisfactory.

Table 3.3: KMO and Bartlett's test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.850
Bartlett's Test of Sphericity	Approx. Chi-Square	3575.351
	df	28
	Sig.	.000

Further, the significance level is less than 0.005, which indicates that the correlation matrix is not an identity matrix, and there exists some correlation between the variables. Hence, the sample is suitable for Factor Analysis.

3.5.3.3 Factor extraction

Table 3.4 presents the eight factors, corresponding to the eight variables that were extracted by the analysis. As seen, there is only one factor, which has an eigenvalue greater than one, suggesting a single factor solution. However, since the second factor has an eigenvalue almost equal to 1, and the objective of the study was to extract two factors, the first two factors of the analysis were considered for the study. Accordingly, the first factor accounts for 43.72% of the variance, while the second factor extracts 12.40%. Hence, the total variance extracted by the two factors is 56.11%, which may be considered suitable for this kind of analysis.

Table 3.4: Extractions of Factors

	Initial Eigenvalues		
Factor	Total	Variance (%)	Cumulative variance
1	3.497	43.717	43.717
2	0.992	12.394	56.111
3	0.814	10.171	66.282
4	0.709	8.868	75.150
5	0.617	7.713	82.863
6	0.557	6.964	89.828
7	0.431	5.381	95.209
8	0.383	4.791	100.000

3.5.3.4 Factor interpretation

To be able to extract more meaningful information from the factors, a varimax rotation was performed, and the relevant results are presented in Table 3.5. The coefficients in the table represent the loading of each variable on to the factors. A loading of 0.4 and higher was considered significant in this study. Accordingly, there are three variables that load on the first factor – 'Employee productivity in utilities', 'Financial state of utilities' and 'Research and Development in utilities', in order of magnitude of loadings. This arrangement partially satisfies the HYP-2 hypothesis developed earlier in section 3.5.3.1. Hence, this factor can be said to be the P_{DIN} factor.

Similarly, the variables loading on to the second factor are 'Trust in water supplier', 'Good quality tap water', 'Research and Development in utilities', 'Equity of distribution' and 'Price of water'. This pattern partially satisfies the HYP-1 hypothesis, indicating that the second factor is the P_{INT} factor. The 'Research and Development in utilities' variable loads on both factors and this is a cross loading variable.

Table 3.5: Factor matrix with varimax rotation

	Factor	
	1	2
Good quality tap water	0.096	0.595
Price of water	0.202	0.403
Customer service	0.355	0.397
Trust in water supplier	0.292	0.643
Research and Development in utilities	0.487	0.528
Financial state of utility	0.708	0.258
Employee productivity in utilities	0.750	0.206
Equity of distribution	0.390	0.476

Although cross-loading variables are not desirable and are usually dropped, retaining the variable is the prerogative of the researcher, especially if there are very few cross loaders (Costello and Osborne, 2005). In this study, the cross loading variable was retained so that there are at least three variables contributing to the P_{DIN} factor, since factors with less than 3 variables are usually unstable. Further, there is a good possibility that given the nature of technological innovation in Japan, consumers may be interested in the 'Research and Development in utilities' variable.

The rotated factor solution partially proves both the hypotheses – HYP-1 and HYP-2 – made for the study.

3.5.3.5 Quantifying P_{INT}

Regression equations were developed to quantify P_{INT}, which used the factor score coefficients resulting from the analysis, which are presented in Table 3.6.

Based on the factor score coefficients for each variable in Table 3.6, the following regression equations were developed

P_{INT} = (0.347 x Trust in water utility) + (0.313 x Good quality water) + (0.197 x R&D in water utility) + (0.162 x Equity of distribution) + (0.144 x Price of water)…………………………...……………..(3.1)

P_{DIN} = (0.484 x Employee productivity in water utility) + (0.387 x Financial state of water utility) + (0.112 x R&D in water utility)……………………………………………………………..…………..(3.2)

Table 3.6: Factor score coefficient matrix

	Factor	
	1	2
Good quality tap water	-0.128	0.313
Price of water	-0.014	0.144
Customer service	0.048	0.112
Trust in water supplier	-0.054	0.347
Research and Development in utilities	0.112	0.197
Financial state of utility	0.387	-0.083
Employee productivity in utilities	0.484	-0.156
Equity of distribution	0.046	0.162

In context of this study, only equation 3.1, corresponding to P_{INT}, is significant.

3.5.3.6 Check for reliability of results

In accordance to section 3.4.5, the Cronbach's Alpha was used to check for internal consistency. The results of the reliability analysis are presented in Table 3.7.

Table 3.7: Reliability analysis

Public Interest (P_{INT})			Public Disinterest (P_{DIN})		
Cronbach's alpha	Cronbach's Alpha Based on Standardized Items	N of Items	Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.734	0.735	5	0.760	0.760	3

The variables contributing to both the factors – P_{INT} and P_{DIN} – have high values of Cronbach's alpha, with magnitudes over 0.70, suggesting that the factors are represented well by the respective variables.

3.5.4 Relationship between P_{INT} and components of 9-cPIS

3.5.4.1 Identification of target water utilities for the study

In order to establish the relationship between the P_{INT} and components of the 9-cPIS, eleven (11) target utilities were identified. The choice of the utilities depended upon the number of questionnaire responses received from the service area of the utilities – areas from where maximum responses were received were selected as the target areas, and the water utilities that supplied water to these areas were chosen as target water utilities. Table 3.8 presents the target water utilities along with the number of responses received from each.

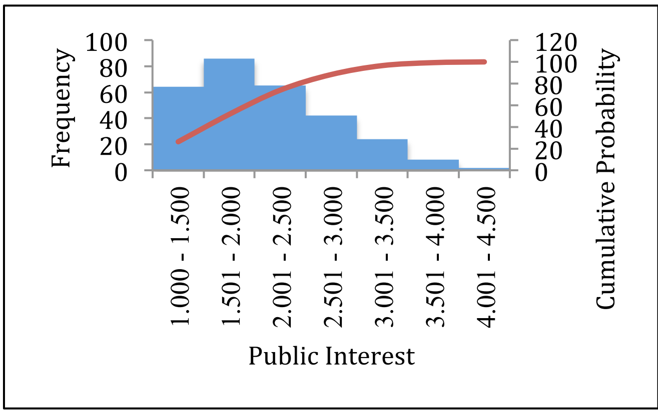
Table 3.8: Selected target water utilities based on questionnaire responses

Target Area	Prefecture	Number of responses
Osaka City Waterworks Bureau	Osaka	263
Kobe City Waterworks	Hyogo	132
Waterworks Bureau, City of Kyoto	Kyoto	118
Sakai City Waterworks	Osaka	52
Amagasaki Waterworks	Hyogo	40
Waterworks Bureau of Nishinomiya City	Hyogo	43
Suita Municipal Waterworks	Osaka	39
Hirakata City Waterworks	Osaka	29
Otsu City Waterworks	Shiga	28
Nara City Waterworks Bureau	Nara	38
Wakayama City Waterworks Bureau	Wakayama	24

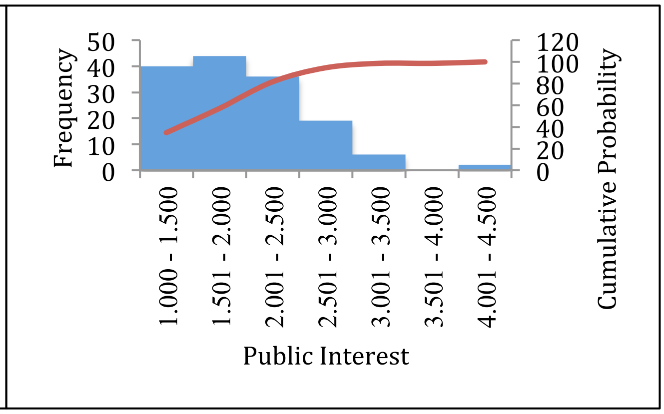
The P_{INT} for each response, in each target utility, was calculated using the regression equation 3.1, developed in section 3.5.3.5. The frequency distribution of the P_{INT} was then plotted for each target utility, as seen in Figure 3.14. The aim of this exercise was to estimate the central tendency of the P_{INT} for each target utility. Based on the frequency distributions in Figure 3.14, it is clear that in all the cases, the data is positively skewed, with a majority of the data concentrated towards the left. There are very few data values, which are towards the right. Hence, considering the mean or median of the entire data set as the central tendency may be misleading.

To address this issue, the cumulative probability distribution for each water utility was plotted as indicated by the thick lines in Figure 3.14. Then, all data values corresponding to 90% probability were selected. The mean, median, mode and standard deviation were then calculated from this range of values, after which the most probable value was fixed depending upon the shape of the distribution. Given that all the distributions are more or less normally distributed, the average or mean value was considered as the most probable value.

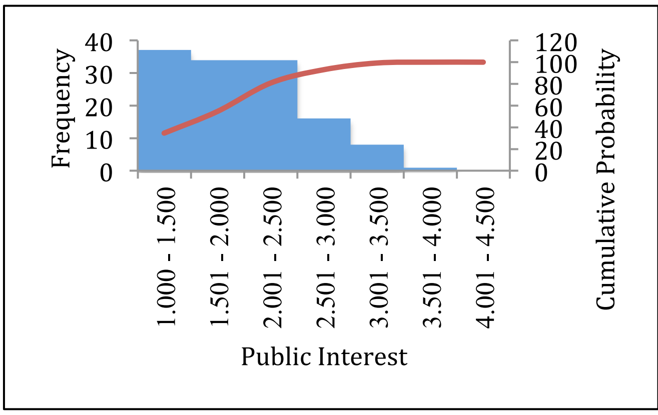
Table 3.9 presents the key statistics of the P_{INT} for the range of values corresponding to 90% cumulative probability, for each of the selected utilities. It is observed that there is very little difference between the mean and median values for all utilities, except Otsu and Wakayama. Moreover, the standard deviation for all cases is almost the same, suggesting that the mean value of the P_{INT} can be used to generalize the P_{INT} for each utility. Hence, the average or mean value of the P_{INT} has been considered for further analysis.



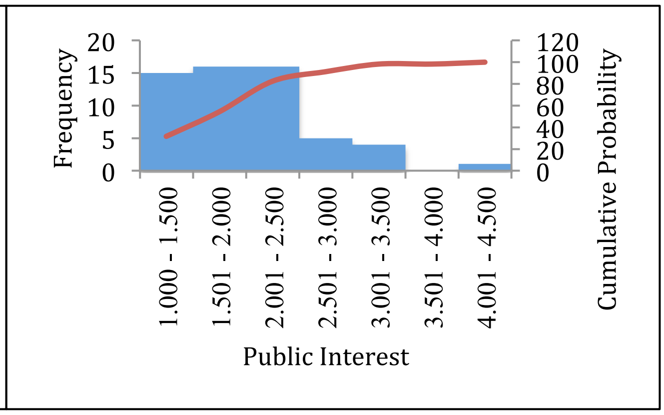
(a) Osaka City Waterworks Bureau



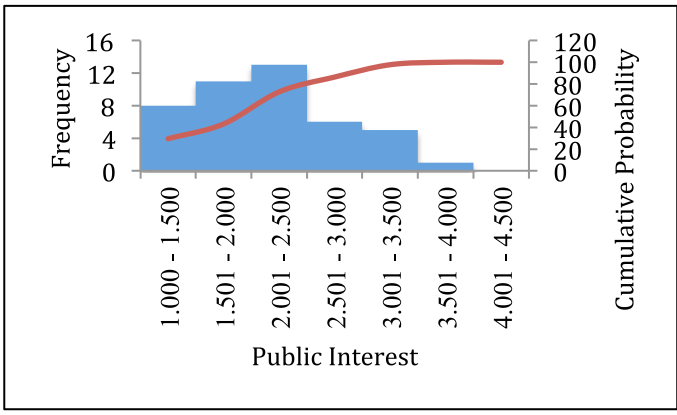
(b) Kobe City Waterworks



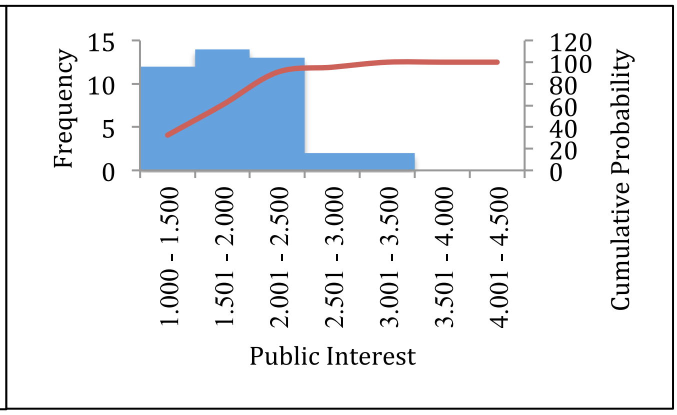
(c) Waterworks Bureau, City of Kyoto



(d) Sakai City Waterworks

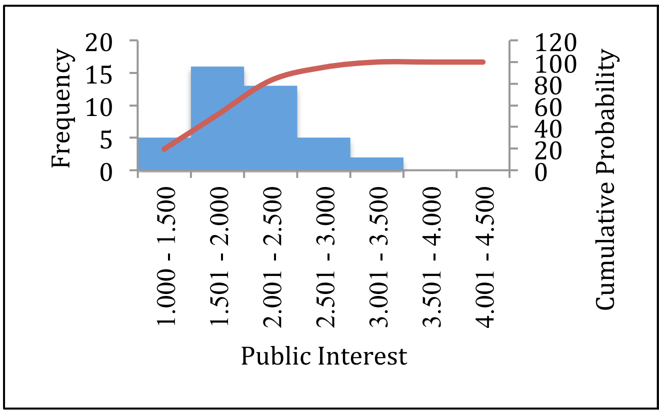


(e) Amagasaki Waterworks

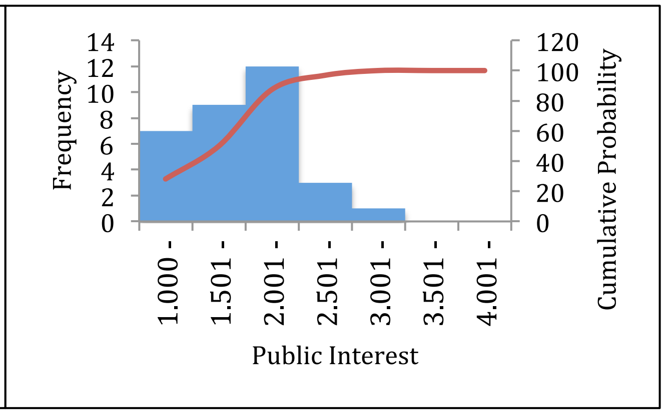


(f) Waterworks Bureau of Nishinomiya City

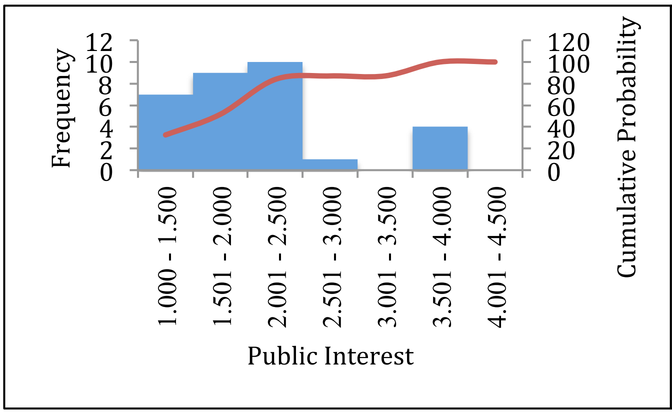
Figure 3.14: Frequency distribution of P_{INT} for selected target water utilities



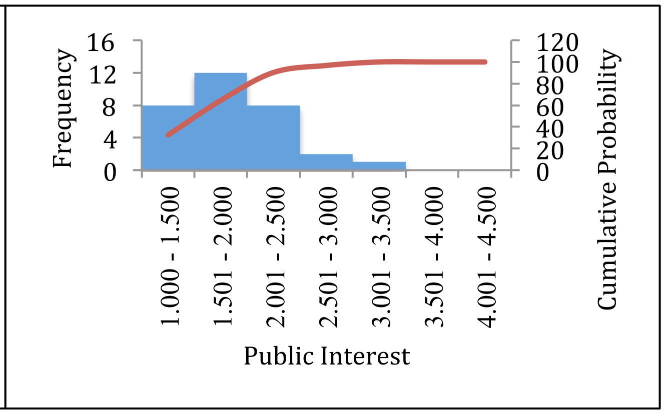
(g) Suita Municipal Waterworks



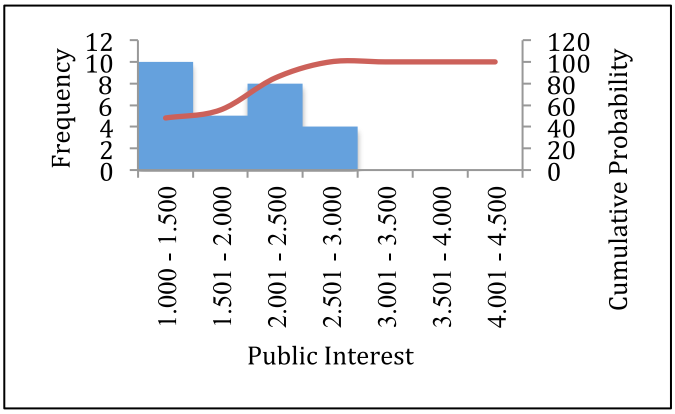
(h) Hirakata City Waterworks



(i) Otsu City Waterworks



(j) Nara City Waterworks Bureau



(k) Wakayama City Waterworks Bureau

Figure 3.14: Frequency distribution of P_{INT} for selected target water utilities continued…

Table 3.9: Key statistics of central tendency of P_{INT}, for selected target water utilities

Water Utility	Mean	Median	Mode	St. Dev
Osaka City Waterworks Bureau	1.91	1.87	1.16	0.52
Kobe City Waterworks	1.81	1.85	1.16	0.46
Waterworks Bureau, City of Kyoto	1.82	1.84	1.16	0.50
Sakai City Waterworks	1.83	1.85	1.16	0.47
Amagasaki Waterworks	1.98	2.03	1.36	0.55
Waterworks Bureau of Nishinomiya City	1.76	1.71	1.16	0.43
Suita Municipal Waterworks	1.96	1.98	1.90	0.39
Hirakata City Waterworks	1.82	1.85	1.16	0.45
Otsu City Waterworks	1.85	1.70	1.36	0.54
Nara City Waterworks Bureau	1.71	1.69	1.16	0.41
Wakayama City Waterworks Bureau	1.70	1.51	1.16	0.49

3.5.4.2 Magnitude of components of the 9-cPIS, for selected target utilities

The 9-cPIS has 33 items, for which the data was obtained from each of the eleven target utilities. Then using the equations 2.1 through 2.9 (in Chapter 2), the magnitudes of each component of the 9-cPIS, for each water utility was calculated. Table 3.10 presents the calculated values for the selected target utilities.

Table 3.10: Magnitudes of the components of 9-cPIS for selected target water utilities

Water Utility	EV	EP	FS	AM	PIN	GWS	CSWQ	ERI	ERWS
Osaka	690.484	56496.640	107.868	11.144	128.407	-61.086	14.938	5.240	31.594
Kobe	789.145	62334.081	98.341	9.120	29.482	-35.680	-12.086	9.432	39.202
Kyoto	813.722	61957.978	104.742	2.014	204.487	-39.594	10.891	2.272	11.487
Sakai	838.762	91292.746	101.153	10.412	46.216	-5.577	13.814	3.983	48.371
Amagasaki	796.458	118256.248	107.411	0.741	49.266	-62.197	4.100	3.595	37.566
Nishinomiya	794.791	68373.537	101.725	2.717	61.133	-35.169	-10.200	4.310	7.342
Suita	622.352	66477.968	98.417	0.247	43.792	-46.940	25.235	2.084	31.160
Hirakata	776.260	96597.429	109.816	0.000	103.809	-68.323	3.637	4.556	36.807
Otsu	729.833	78476.319	112.749	3.040	111.596	-67.401	0.672	5.714	14.501
Nara	833.306	62731.645	107.750	0.000	139.257	-20.073	-10.633	3.717	68.296
Wakayama	810.647	7829.330	127.495	0.000	212.015	-47.300	-31.763	8.152	2.511

EV: Economic Value of Water; EP: Employee Productivity; FS: Financial Sustainability; AM: Adaptive Management
PIN: Private Investment; GWS: Green Water Supply; CSWQ: Consumer Satisfaction for Water Quality
ERI: Emergency Response Index; ERWS: Earthquake Resistant Water Supply

All the values in the table are non-standardized but the values have been standardized in the range 0 to 1 later, using the normalization formula indicated previously in Equation 2.10. The reason for doing this was to avoid any negative values that result from negative component score coefficients. It was important to have all positive values to ensure that it is easy to test the regression models developed between the $\mathbf{P_{INT}}$ and 9-cPIS.

3.5.4.3 Regression models to relate $\mathbf{P_{INT}}$ and each component of 9-cPIS

Figure 3.15 shows the relationship between the $\mathbf{P_{INT}}$ and each component of the 9-cPIS. Accordingly it can be seen that, based on the coefficient of determination (R^2), there is no strong relationship between the P_{INT} and any of the components of the 9-cPIS. This suggests that in order to extract a more accurate relationship, additional variables will have to be considered. However, the objective of this study is not to derive an exact relationship but to understand how the $\mathbf{P_{INT}}$ and 9-cPIS are related, and thereby suggest a reasonable relationship that can be used to understand the public behavior (or interest) in the water supply systems.

As seen in Figure 3.15, there appears to be a negative correlation between the $\mathbf{P_{INT}}$ and the Economic Value of Water. This is not a good sign because it indicates that the public is not really aware of the true cost of water supply and its importance. A possible reason for this is that the cost of water is not significant enough to arouse public concern or interest. However, as long as the price of water reflects the cost of production decrease in the Economic Value of Water may not be of concern. A simple linear relationship between the $\mathbf{P_{INT}}$ and the Economic Value of Water is presented in Equation 3.3

$EV = -2.112\ \mathbf{P_{INT}} + 4.563$……………………………………………………………..………….(3.3)

The Employee productivity surprisingly is positively correlated to the $\mathbf{P_{INT}}$. This is in contradiction with the results of the Factor Analysis in section 3.5.3.4, where it was established that the consumers are not interested in the productivity of employees of their water utilities. A possible explanation for this could be that from the questionnaire results, already presented in Figure 3.10, there were a large number of respondents who chose 'undecided' when asked about how important was EP to them. This could have affected the reliability of results. The linear relationship between the Employee Productivity and the $\mathbf{P_{INT}}$ is shown in Equation 3.4

$EP = 1.627\ \mathbf{P_{INT}} - 2.416$……………………………………………………………..………….(3.4)

The next component of the 9-cPIS, Financial Sustainability, also displays an inverse relationship with the $\mathbf{P_{INT}}$. This trend agrees well with the results of the Factor Analysis mentioned earlier. Equation 3.5 shows the relationship between the Financial Sustainability and the $\mathbf{P_{INT}}$.

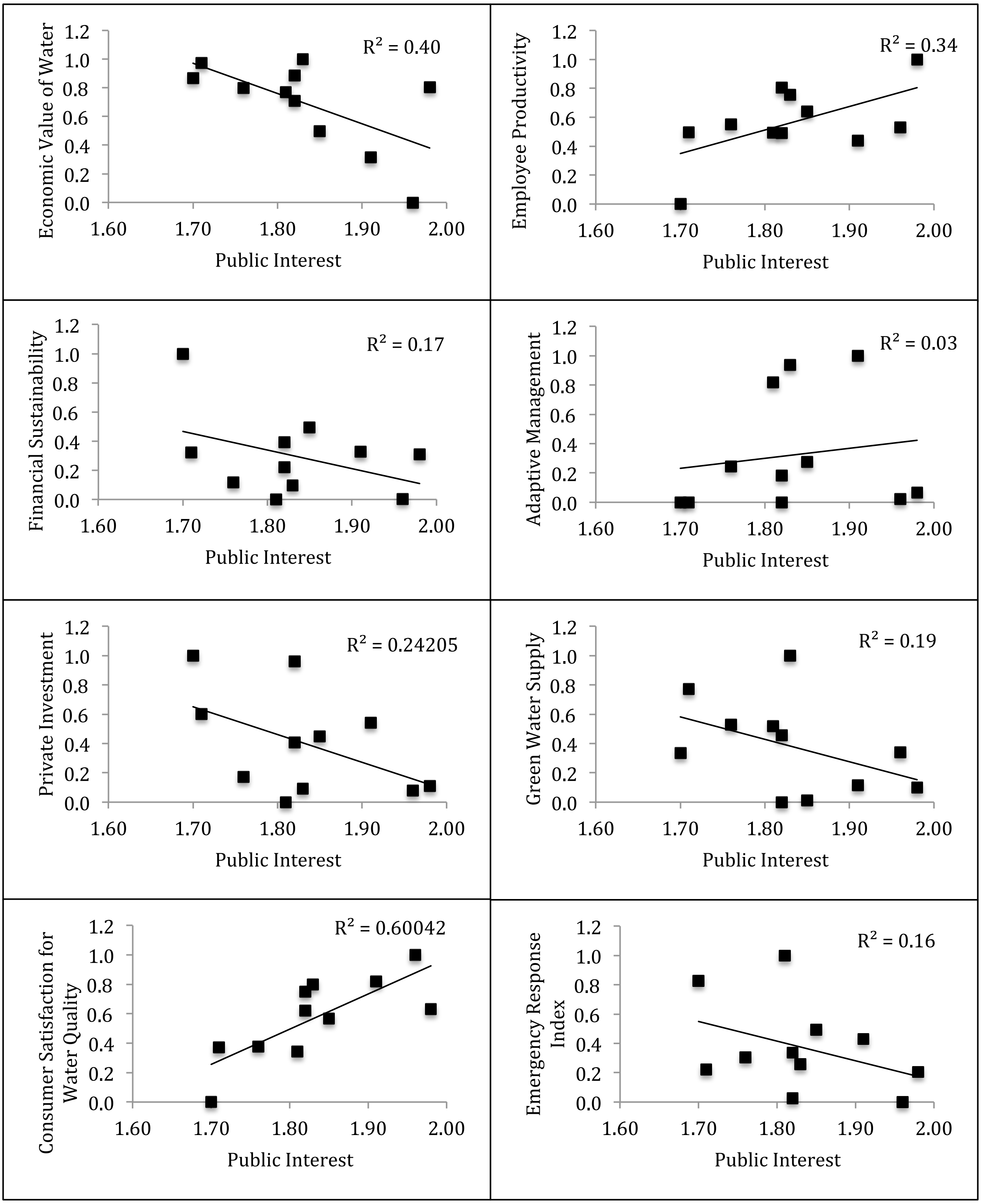


Figure 3.15 Relationships between P_{INT} and each component of the 9-cPIS

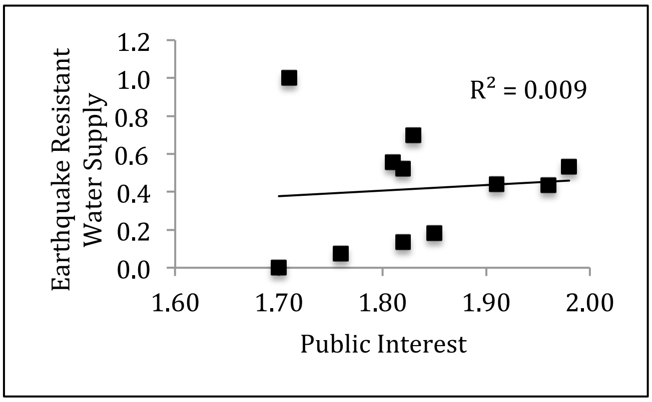


Figure 3.15: Relationships between P_{INT} and each component of the 9-cPIS continued…

FS = -1.277 P_{INT} + 2.637…………………………………………..……………………...………….(3.5)

Conversely, there does not appear to be any relationship between the Adaptive Management and the P_{INT}. A possible reason for this is that, as seen in Figure 3.15, there are many entries of 'zero' for the AM, which has affected the correlation coefficient. No relationship has been suggested in this case because of the extremely weak correlation between the Adaptive Management and the P_{INT}.

There appears to be a negative relationship between the Private Investment and the P_{INT}. This is quite understandable because it is usually the investors who have interest in the Private Investment - the general public does not. However, from a sustainability point of view it is very useful for the water utilities if the public takes a keen interest in investment. The relationship between the Private Investment and the P_{INT} is presented in Equation 3.6

PIN = -1.895 P_{INT} + 3.871……………………………………..……………………….....………….(3.6)

There appears to be a negative relationship between the Green Water Supply and the P_{INT}. This a major cause of concern because it suggests that the public is not interested in GHG emissions reductions and an environmentally friendly supply. The water utilities in Kansai region, thus, need to spread awareness among consumers regarding the need of reducing the GHG emissions in order to ensure sustainability of water supply. Equation 3.7 presents the relationship between the GWS and the P_{INT}.

GWS = -1.53 P_{INT} – 3.183……………………………………………….…………………...………….(3.7)

There is a strong positive relationship between the Consumer Satisfaction for Water Quality (CSWQ) and the P_{INT}. This is in good agreement with the results of the Factor Analysis, where good quality tap water was one of the most important variables of the P_{INT} factor. The relationship between the Consumer Satisfaction for Water Quality and the P_{INT} is depicted in Equation 3.8

$CSWQ = 2.390\ P_{INT} - 3.808$………………………………………….………………...……….(3.8)

Surprisingly there appears to be a negative relationship between the Emergency Response Index and the P_{INT}. A possible explanation is that in the Kansai region, there have not been too many cases in the last decade or so which could have aroused public concern with respect to this component. Equation 3.9 presents the relationship between the Emergency Response Index and the P_{INT}.

$ERI = -1.340\ P_{INT} + 2.828$………………………………..……..………………………...………….(3.9)

Finally, as seen in Figure 3.15, there is no discernable relationship between the Earthquake Resistant Water Supply and the P_{INT}.

3.5.4.4 Multiple Linear Regression to determine the relationship between P_{INT} and 9-cPIS

In the previous section, the relationships between each component of the 9-cPIS and the P_{INT} were established. It was seen that none of the components had a very strong relationship with the P_{INT}, suggesting that the P_{INT} cannot be explained by a single component. This section endeavors to develop a relationship between the all the components of the 9-cPIs together with the P_{INT}. Multiple Linear Regression (MLR) was used for this purpose.

MLR attempts to model the relationship between two or more explanatory variables and a dependent variable by fitting a linear equation to the observed data. A MLR model takes the form as depicted in Equation 3.10

$Y = ß_0 + ß_1x_1 + ß_2x_2 + \ldots\ ß_nx_n + e$……………………..…………………………...………………..(3.10)

Where

Y = Dependent variable

$ß_0$ = Intercept

$ß_1 \ldots ß_n$ = Coefficients

$x_1 \ldots x_n$ = Explanatory variables

e = error

MLR is usually based on least squares: the model is fit such that the sum-of-squares of differences of observed and predicted values is minimized. Ostrom (1990, p. 14) lists six basic assumptions for the regression model

- The relationship between the dependent and explanatory variables is linear
- The errors are uncorrelated with individual explanatory variables
- The expected value of residuals is zero. The residuals measure the closeness of fit of the predicted values and actual values
- The variance of the residuals is constant
- The residual terms are random, or uncorrelated in time
- The error term is normally distributed

Based on the data presented previously in Tables 3.9 and 3.10, MLR was performed to establish a relationship between the P_{INT} and 9-cPIS. The P_{INT} was taken as the dependent variable whereas each of the nine components of the 9-cPIS was considered as an explanatory variable. In order to ensure that there are enough cases to perform the analysis, 5-10 questionnaire responses were selected from the service areas of the 11 target utilities. The criteria used for selection was that the P_{INT} of the response of a particular area should be within one standard deviation of the mean P_{INT} of that area. This was done to ensure that the P_{INT} of the responses was close to the mean P_{INT} of the respective areas. In doing so, 77 responses were selected. The analysis was performed with PASW 18.0 Statistics Base.

The model performance was evaluated using the coefficient of determination (R^2) and the adjusted coefficient of determination (adjusted R^2). In statistics, the coefficient of determination R^2 is the proportion of variability in a data set that is accounted for by a statistical model. In this definition, the term "variability" is defined as the sum of squares. Adjusted R^2 is a modification of R^2 that adjusts for the number of terms in a model. R^2 always increases when a new term is added to a model, but adjusted R^2 increases only if the new term improves the model more than would be expected by chance.

During the analysis, it was observed that inclusion of all explanatory variables in the model resulted in a negative adjusted R^2, which indicated that there are some explanatory variables that are unnecessary causing the model performance to drop. Hence, the analysis was performed in stages by removing the least necessary variable (based on the individual variable's correlation with the P_{INT}) at one time. In doing so, the Earthquake Resistant Water Supply and Adaptive Management components were found redundant and were omitted from the modeling process. It must be noted that it was also not possible to establish relationships of both these components with the P_{INT}, as seen in the previous section.

Hence the final model constituted of 7 explanatory variables: Economic Value of Water, Employee Productivity, Financial Sustainability, Private Investment, Green Water Supply, Consumer Satisfaction for Water Quality and Emergency Response Index. Table 3.11 presents the goodness of fit for the model developed.

Table 3.11: MLR model summary

R	R^2	Adjusted R^2	Std. Error of the estimate
0.772	0.596	0.555	0.065

It is seen that the model performs reasonably well with the seven explanatory variables, resulting in an adjusted R^2 of 0.555. Further, there is very little difference between the R^2 and adjusted R^2 values, suggesting reliability of sample size. The standard error of estimate also is quite low at 0.065, indicating the suitability of this model. Table 3.12 presents the coefficients for the model.

Table 3.12: Coefficients for MLR model

Variable	Unstandardized coefficients
Constant	2.083
Economic Value of Water	0.001
Employee Productivity	2.17×10^{-6}
Financial Sustainability	-0.004
Private Investment	0.001
Green Water Supply	-0.001
Consumer Satisfaction for Water Quality	0.004
Emergency Response Index	0.021

Based on the coefficients in Table 3,12, equation 3.11 expresses the relationship between the P_{INT} and 9-cPIS

$$\mathbf{P_{INT} = 2.083 + 0.001\ EV + 2.17 \times 10^{-6}\ EP - 0.004\ FS + 0.001\ PIN - 0.001\ GWS + 0.004\ CSWQ + 0.021\ ERI} \quad (3.11)$$

3.5.4.5 Implications of the study

From the information presented in the previous two sections, it is seen that out of the nine components of the 9-cPIS, only 2 exhibit a positive relationship with the $\mathbf{P_{INT}}$: Consumer Satisfaction for Water Quality and Employee Productivity. The consumers appear to have some genuine interest in these components. The water utilities can use this information to build their relationship with the consumers. For example, the results suggest that the consumers are interested in Consumer Satisfaction for Water Quality. Utilities can promote their product by highlighting the technology used in the production of water, and the resulting water quality. They can also disseminate information about latest measures that have been implemented, or are being planned. Doing so will not only garner the interest of the public but will also help the public to have a good impression of the water utilities. Having a good impression is particularly useful to earn the trust of consumers because any adaptation measures in response to climate change that need to be implemented will require public support. Receiving public support becomes easier when the consumers trust the utilities. An additional advantage is that when the utilities have to make investments in technology to improve water quality for which a hike in water fees is needed, there is a very strong possibility that the consumers will readily support this endeavor. Hence, the utilities will depend less on subsides from the government, and move towards self-dependency.

Two components of the 9-cPIS display no relationship with the P_{INT}: Adaptive Management and Earthquake Resistant Water Supply, possibly because of anomalies in data.

Five components of the 9-cPIS exhibit a negative relationship with the P_{INT}: Economic Value of Water, Financial Sustainability, Private Investment, Green Water Supply and Emergency Response Index. While it is understandable that the public has little interest in the first three, the lack of Public interest in the Green Water Supply is a concern. As mentioned earlier, any adaptation measure for climate change will require public support and it is imperative that the public is aware of the implications of climate change on water supply so that they will be willing to adapt. The utilities, thus, need to make more focused efforts to disseminate the information about climate change among consumers so as to make them aware of the potential problems. This can be done through advertisements on the television, fliers or providing the relevant information on the utility's websites. Another novel way of raising awareness is to attach an informative pamphlet along with the water bills, and send them to the consumers. In a nutshell, every possible effort must be made to create awareness among consumers about the potential impacts of climate change on water resources, to ensure public support for the implementation of the adaptation strategies employed by the utilities.

A multiple regression equation between the P_{INT} and all components of the 9-cPIS together has been developed to help in evaluating tradeoffs between the consumer expectations and reductions in GHG emissions. Details of the analysis and proposed methodology will be discussed in detail in Chapter 5.

3.6 Summary

The thematic focus of this study was to introduce a concept called "Public Interest P_{INT}" in water supply. In light of climate change and its impacts, the water utilities will have to adopt various adaptation measures, especially with respect to making a tradeoff between water quality and energy use. Understanding the public interests and concerns is very crucial in planning for any adaptation measures because without public support it will be very difficult to achieve success.

An Internet based questionnaire survey was conducted in the Kansai region of Japan. The questionnaire contained eight questions, of which five were hypothesized to be related to public interest while the others not related to the public interest. 1648 responses were received, based on which Factor Analysis was carried out to isolate the P_{INT} factor. From the Factor Analysis results, two factors were extracted. The first factor was found to be the Public Disinterest factor P_{DIN}**,** which contained three variables: 'employee productivity in utilities', 'financial state of utilities' and 'Research and Development in utilities'. There are five variables contributing to the second factor, P_{INT}**: '**trust in water supplier', 'good quality tap water', 'Research and Development in utilities', 'equity of distribution' and 'price of water'.

From the relationships developed between the P_{INT} and the components of the 9-cPIS, it emerged that two of the components: Consumer Satisfaction for Water Quality and Employee Productivity displayed a positive relationship with the P_{INT}. On the other hand, it is matter of concern that there is a negative relationship between the Green Water Supply and the P_{INT}. The utilities, thus, need to make more focused efforts to disseminate the information about climate change, and its impacts on water supply, among consumers so as to make them aware of the potential problems so that adaptation measures can be implemented successfully.

The study also developed a multiple linear regression model between the P_{INT} and all components of the 9-cPIS together. The main purpose of this was to prepare a background to facilitate tradeoff between the consumer expectations and reduction of energy use in utilities. Details of the tradeoff analysis – the methodology and results – are discussed in detail further in Chapter 5.

A possible limitation of the study could be with regards to a bias in the questionnaire responses because of the recent earthquake and tsunami disaster in Sendai in March 2011, which led to the breakdown of a nuclear power plant. There was widespread concern in both national and international circles about nuclear contamination. In response, the radiation level in drinking water was thoroughly monitored by utilities all over Japan, and ardent efforts were taken by the government to mitigate public anxiety. Despite this, there is a possibility that this incident may have played on the minds of the respondents when filling out the questionnaires. However, it is difficult to confirm or ascertain the presence of this bias because the questionnaire was conducted in December 2011, 9 months after the disaster, and the dissemination area (Kansai region) is quite far away from the disaster site.

CHAPTER IV

REGRESSION MODELING FOR CLIMATE CHANGE SCENARIOS

4.1 Background

4.1.1 Thematic objective

The ultimate aim of this doctoral research is to, through numerical modeling, provide a framework for water utilities in Japan to make tradeoffs between meeting customer expectations with respect to water quality and reducing energy use, in light of climate change. The framework involves developing mathematical models, which would be then tested against different scenarios of change. This aim of this chapter is the development of these models.

Most of the water supply models developed for climate change have considered the water availability and water scarcity aspects (e.g. Charlton and Arnell 2011; Vairavamoorthy et al., 2008; Dessai and Hulme 2007; etc.). Using advanced scientific techniques these models attempt to provide feasible solutions to maintain adequate supply of water. However, until recently there have been relatively few studies based on evaluating the water quality under climate change scenarios. A comprehensive literature review carried out by Delpla et al. (2009) provides a description about the limited range of topics researched recently. Fewer studies have been carried out to explore the nexus between drinking water quality and energy use. Admittedly there have been a few publications based on reducing energy use for advanced water treatments (e.g. Shaffer et al., 2012; Kolagirou 2005) but to the best of the author's knowledge there have not been any studies on designing or exploring the tradeoff between water quality and reduction of energy use.

A model is basically a mathematical relationship between a dependent variable and one or more independent variables. To correctly describe the phenomenon of the process being modeled, it is very important that the appropriate variables (dependent and independent) are selected. In this study, it is crucial that the independent variables are related to climate change because the modeled process involves the analysis of different scenarios of change. Further, the choice of the dependent variable must be so that it can be related to all the independent variables. The next section describes the selection of variables for this thematic study.

4.1.2 Selection of variables

4.1.2.1 Independent variables

Two variables – 'Raw water turbidity' and 'GHG emissions' were selected as independent variables.

(a) Raw water turbidity: The most common effects associated with climate changes in Japan are increased precipitation volume and increase in extreme events. Both of these have a direct repercussion on the water quality, leading to degradation of water quality in rivers and lakes due to increased sediment transport and organic matter concentration. The Japan Water Research Center (JWRC, 2009) conducted a questionnaire survey in 2008 with 110 utilities, in which the utilities were asked in one of the questions, to identify changes in raw water quality after short-term weather changes like heavy rainfall etc. The results of the questionnaire are shown in Figure 4.1. Accordingly, 97.5% of the utilities indicated that turbidity of raw water is most affected after weather changes like rainfall or snowmelt, suggesting that raw water turbidity can be used as a good indicator to monitor the affects of climate change on water resources.

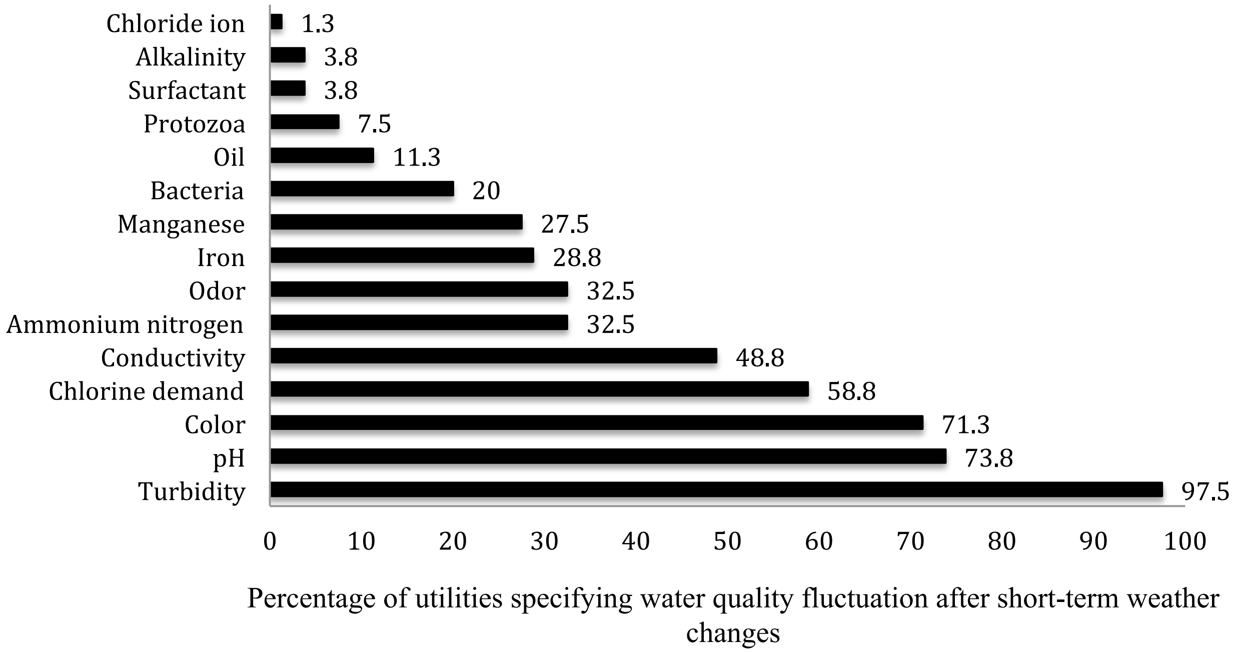


Figure 4.1: Reported change in water quality after short-term weather changes (Source: JWRC, 2009)

(b) GHG emissions: In context of adaptation to climate change, reducing the GHG emissions is no longer a choice — It is a necessity. Efforts are being made worldwide, at both global and regional scale to encourage the reduction of GHG emissions. The United Nations Framework on Climate Change (UNFCC, 2012b), through its various agendas like the Kyoto Protocol, Bali Road Map, Cancun agreements, is a leading player in raising awareness among member nations and providing capacity building support to pursue the required targets of reduction in GHG emissions. Japan has committed to reducing its GHG emissions by 25% from 1990 levels up to the year 2020. Hence reduction in GHG emissions is an important Driver of Change for all public and private sectors. Although the drinking water sector contributes to less than 1% of the total GHG emissions of the nation, reducing the GHG emissions is nevertheless a significant endeavor because it will lead to a change in attitudes of both consumers and suppliers towards the sustainable use of water.

4.1.2.2 Dependent variables

‘Power consumption’ was selected as the primary dependent variable because both the GHG emissions and the raw water turbidity are expected to be theoretically related to the power consumption. Further, since the models will be ultimately tested against the PIs of the 9-cPIS, ‘Water production volume’ was selected as another dependent variable, which depends upon the power consumption. The reason is because it is easy to relate the water production volume to most of the components of the 9-cPIS. Water production volume is the volume of water produced inclusive of all transmission and distribution loses. Hence water production volume is the volume of water supplied to consumers, plus all losses. The average loss for Japanese water utilities is around 8%.

Finally, three PIs in the 9-cPIS - Financial Sustainability, Green Water Supply and Economic Value of Water were selected as the dependent variables, which depend upon the water production volume. The criteria for choosing these PIs was

(a) Suitability in context of climate change: The 9-cPIS has 9 components or PIs, which evaluate different aspects of the supply system generally. However since this study endeavors to develop a tradeoff between water quality and reducing energy use under scenarios of climate change, only those PIs were shortlisted which are expected to be significantly affected by climate change.

(b) Data availability: Since the modeling process requires continuous time series data, it is important to choose PIs for which the data is available for a reasonable length of time. This is an important criteria because, for example although Emergency Response Index (one of the components of the 9-cPIS) is an important PI in context of climate change, there is not enough data available from the selected water utility to warrant its inclusion in the study.

4.2 Regression models

Regression models are statistical models to identify the relationship between a response variable and one or more explanatory variables (Bouveyron and Jacques, 2010). A general regression linear model is given by equation 4.1

$$Y = b_0 + b_1X + \varepsilon \qquad (4.1)$$

Where,

b_0 = intercept
b_1= parameter estimate for variable X
ε = Error term

ε is the residual that cannot be explained by the variables in the model. The following assumptions must hold when building a linear regression model

- The dependent variable must be continuous.
- The data being modeled should meet the 'iid' criterion, which means the error terms ε are (a) independent from one another and (b) identically distributed
- The error term is normally distributed with a mean of zero and a standard deviation of σ^2, $N(0, \sigma^2)$.

When there are two or more independent variables that are required to estimate the dependent variable, the analysis is called multiple linear regression which takes the form of equation 4.2

$Y= b_0 +b_1X_1+b_2X_2 + \varepsilon$…………………………………………………………………….………..(4.2)

The use of regression models in water supply is not new and has numerous applications — Evaluating THMs in drinking water (Morrow and Minear, 1987; Golfinopoulos et al. 1998; Golfinopoulos and Arhonditsis, 2002), modeling water supplies (Iliadis et al. 2011; Prokopy 2005; Vidoli 2011), and forecasting water demand (Herrera et al. 2010; Qi and Chang, 2011) among other potential applications. Given its simple structure and wide range of applications, the use of regression models was thought appropriate for this study. Due to data constraints, for this study, only univariate analysis, using a single independent variable has been used in all the models.

4.3 Overall modeling framework for the study

The thematic objective of this study was to first develop regression models between the independent and dependent variables selected for a specific water utility — the Kobe City Waterworks. The overall modeling framework for this thematic focus is depicted in Figure 4.2. Accordingly, two Drivers of Change (DoC) — Turbidity of raw water and GHG emissions — were identified from literature and managerial targets, as discussed in the previous section. Further, a relation was established between each DoC and the Power consumption, resulting in Models 1 and 2 respectively. Next, a relationship was derived between the Power Consumption and the water production volume (Model 3). Finally, the water production volume was associated with three components of the 9-cPIS, namely Financial Sustainability, Green Water Supply and Economic Value of Water (Models 4, 5 and 6 respectively). The models enclosed in the smaller rectangle is the water quality model unit, while the models bounded by the larger rectangle is the water quantity model unit. Following is a detailed description of each model.

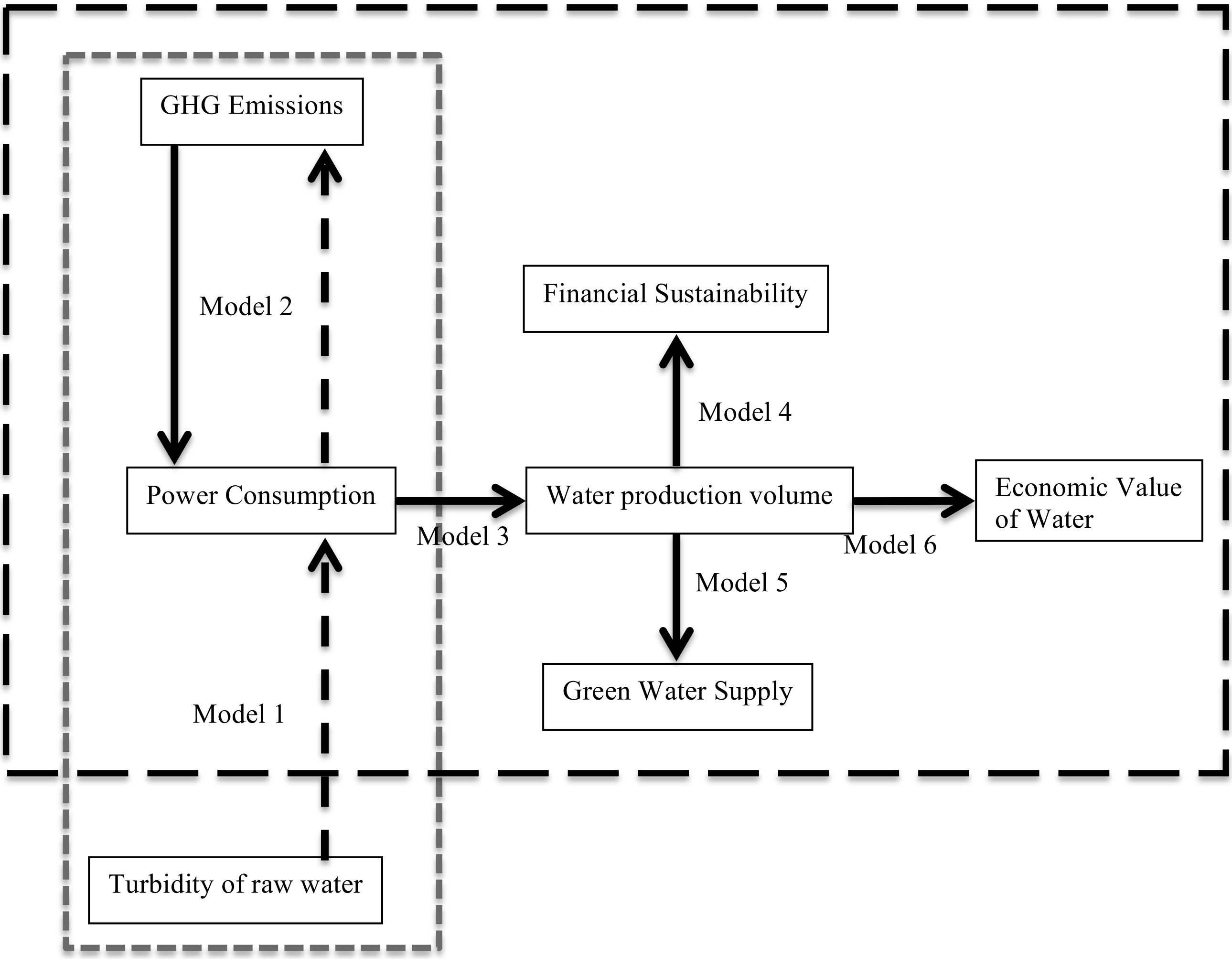


Figure 4.2: Overall modeling framework for the study

Model 1 relates the Turbidity of raw water to the power consumption. Discussions with the utility manager of Kobe City Waterworks indicated that when the turbidity of raw water increases, the utilities increase both the coagulant dosage and the retention times in the flocculation basin. Increasing the retention time in the basins will lead to increased operation hours of the treatment plant, because the target daily amount of water must be supplied. With increased operation hours, it can be inferred that the power consumption will also increase, providing the rationale for developing this model. ***The total power consumption data was used to develop the models***

Model 2 relates the GHG emissions with the Power consumption. Carbon dioxide emissions resulting from the consumption of electricity are the single highest source of emissions for many industries. Most countries use an emission factor to convert power consumption to GHG emissions. The determination of this factor depends upon a variety of factors – type of fuel used for energy generation (coal, gas, oil), mode of generating (hydropower, nuclear etc.), age of the power plants (new plants usually have higher efficiency). It can be thus understood that there is a very strong and cogent relationship between the GHG emissions and power consumption.

Model 3 relates power consumption with the water production volume. The choice of the 'water production volume' variable was based on two criteria. First, a variable was needed which would theoretically have a strong relationship with the power consumption. Second, the variable should also be strongly related with the components of the 9-cPIS considered for this study. Based on judgment and background, it was hypothesized that the water production volume would display a strong correlation with the power consumption and selected components of the 9-cPIS, which will be shown later in the chapter.

Models 4, 5, and 6 relate the water production volume with three components of the 9-cPIS - Financial Sustainability, Green Water Supply and Economic Value of Water. As stated earlier, changes in the water production volume are expected to affect the magnitudes of the components.

4.4 Methodology for model development

Figure 4.3 depicts the flow of activities for the model development for this thematic study. Accordingly, first, a basic check was performed by plotting the scatter plot of the input and output to determine whether or not there could be a relationship between the two. Only if the plot indicated a definite trend, the variables were considered for subsequent analysis. Next, the input data was divided into training and testing sets, with the testing data set making up between 25-30% of the total data. Four types of fits were used to check the fit of the input and output – Linear, Quadratic, Cubic and Power. Each of these fits were then tested against three goodness-of-fit indices as indicated in equations 4.3 through 4.5

(a) Average Absolute Relative Error (AARE)

$$\text{AARE} = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{O_i - M_i}{0_i}\right| X100 \quad \text{……(4.3)}$$

(b) Root Mean Square Error (RMSE)

$$\text{RMSE} = \frac{1}{N}\sum_{i=1}^{N}[(O_i - M_i)^2]^{\frac{1}{2}} \quad \text{……(4.4)}$$

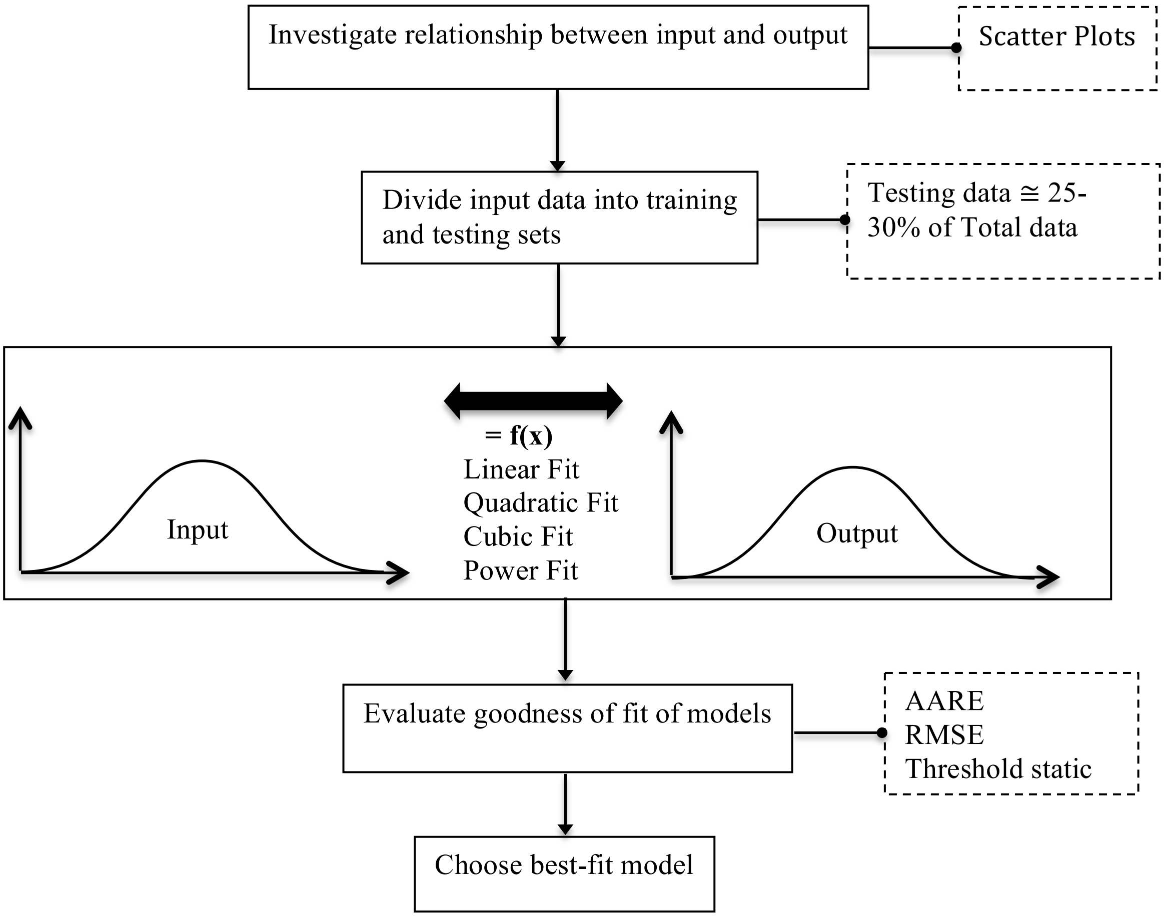


Figure 4.3: Schematic for developing regression models

(c) Threshold static

$$TS_x = (n/N) \times 100 \qquad \text{……(4.5)}$$

Where,

O_i = Observed data

M_i = Modeled data

TS = Threshold static for a level of x %

n = Number of testing data points having a predicted relative error less than x%

N = total number of testing data points.

4.5 Data collection

4.5.1 Data Source

All the data for this study was obtained from Kobe City Waterworks, which is the biggest water utility in the Hyogo Prefecture of Japan. Located on the southern side of the main island of Honshu, approximately

30 km to the west of Osaka, the city of Kobe is home to a little over 1.5 million people. The Kobe City Waterworks is a very old establishment, set up in the year 1900 to provide safe and reliable drinking water supply to the consumers. Because Kobe is wedged in between coasts and mountains, the terrain is steep. Thus, there are three storage reservoirs, located at different levels, into which water is pumped and thereby distributed through gravity. Figure 4.4 shows the distribution area, and main water sources for the Kobe City Waterworks.

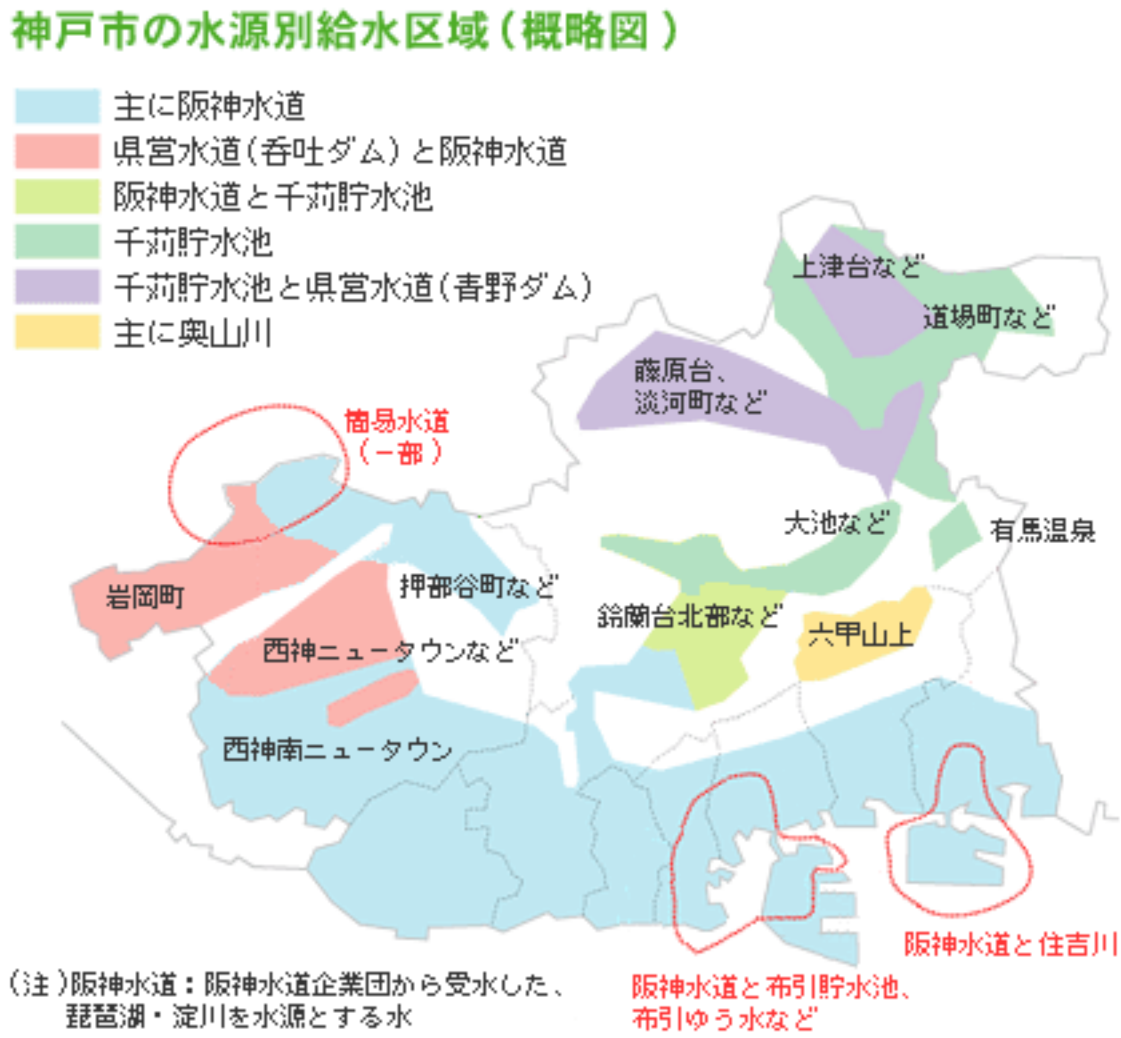


Figure 4.4: Water sources for the Kobe City Waterworks

In Figure 4.4, there are six items in the legend, in Japanese, indicating that the distribution area is serviced by six water sources. The topmost item in the legend corresponds to Hanshin Water Supply Authority, which is the largest source of treated water for the Kobe City waterworks. As seen in Figure 4.4, the water from Hanshin Water Supply Authority is supplied to most of the distribution area in Kobe. The next item in the legend corresponds to the Hyogo Prefectural Authority, from which the Kobe City Waterworks receives water to supply the North West region of Kobe. The Hanshin and Senghari reservoir is the next item on the legend followed by the Senghari reservoir, Senghari and Hyogo reservoir and finally the Okuyama River, which are all among the minor sources of water supply.

There are six water treatment plants under the Kobe City Waterworks – Uegahara, Okuhirano, Senghari, Motoyama, Rokkousan and Sumiyoshi (which is currently out of service). Most of the treatment plants use the traditional style of treatment with sedimentation, coagulation, rapid sand filtration, activated carbon treatment and chlorination among the major processes. The Motoyama treatment plant is the only plant that uses membrane technology to treat water. The distribution leakage rate is a mere 5% suggesting a well-monitored pipe network. The number of staff workers as of 2010 was 746. Figure 4.5 indicates that the production volume and per capita consumption has been on the decline over the last few years, while the population has been on the rise. A possible explanation for the reduced per capita demand is that the fixtures used by the consumers utilize water saving technology.

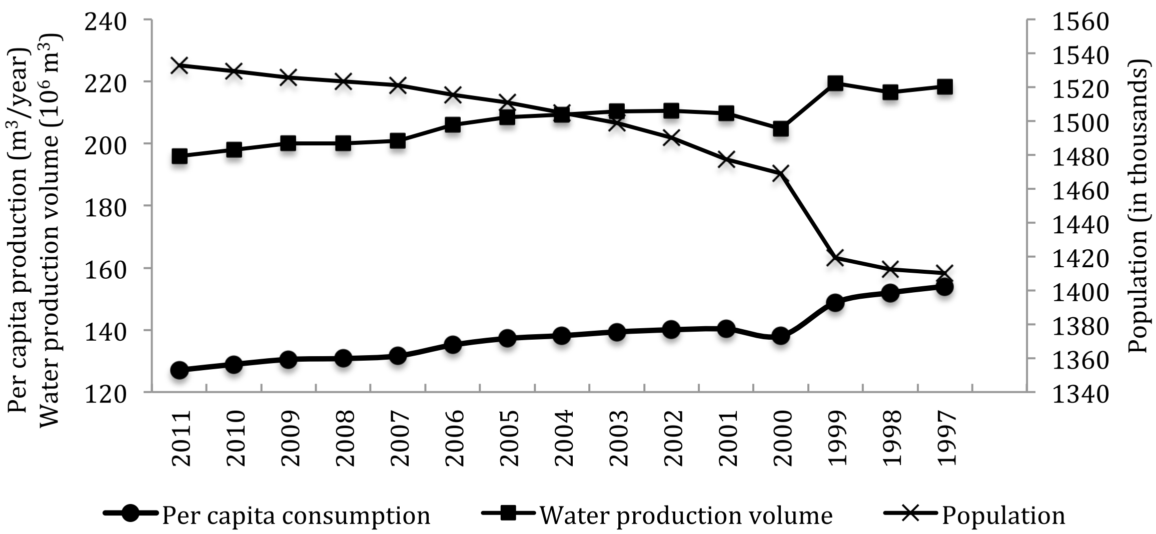


Figure 4.5: Basic water supply information for Kobe City Waterworks

Specific data, especially the water quality data, was collected from the Senghari water treatment plant because it is the largest treatment plant under Kobe City waterworks, having a treatment capacity of 108,000 m^3/day. The plant uses rapid sand filtration and Activated Carbon treatment, and the treated water is supplied to the Kita ward in Kobe.

4.5.2 Data Description

The data collected for each of the six models developed in the study are described in Table 4.1. Most of the data was collected by personally visiting the Waterworks and taking copies of the official data sheets.

Further, discussions with the utility manager and other senior officials yielded a wealth of information regarding the operations and structure of the Waterworks. A site visit was also conducted to one of the treatment plants to get a background about the supply technology and distribution. Details of the various data can be referred to in Appendix C.

Table 4.1: Particulars of data collected for study

Data Description	Unit	Frequency	Duration	Required For
Raw Turbidity	Degrees	Quarterly	2005-2010	Model 1
Power consumption	kWh	Monthly	2005-2010	Model 2, 3,5
GHG emissions	t-CO_2	Monthly	2005-2010	Model 2,5
Water production volume	10^6 m^3	Monthly	2005-2010	Model 3
		Yearly	1994-2004	Model 4,5,6
Operating Revenue	Yen	Yearly	1994-2004	4
Non operating revenue	Yen	Yearly	1994-2004	4
Acquisition revenue	Yen	Yearly	1994-2004	4
Total Revenue	Yen	Yearly	1994-2004	4,6
Operating expense	Yen	Yearly	1994-2004	4
Non operating expense	Yen	Yearly	1994-2004	4
Acquisition expense	Yen	Yearly	1994-2004	4
Unit cost of water	Yen/m^3	Yearly	1994-2004	4,6
Unit price of water	Yen/m^3	Yearly	1994-2004	4
Water fee for up to 10m^3 consumption	Yen/m^3	Yearly	1994-2004	6
Water fee for up to 20m^3 consumption	Yen/m^3	Yearly	1994-2004	6
Supply population	Number	Yearly	1994-2004	3

For some data, especially the GHG emissions, the emission factor recommended by the Ministry of Environment was used to convert the Power consumption into GHG emissions. This information was availed from the Internet. All data was first screened for outliers before they were used in the model development. Standard time series data and scatter plots were used in this preliminary analysis.

4.6 Results and Discussion

4.6.1 Model 1 (Raw water turbidity – Power consumption model)

Figure 4.6 portrays the relationship between the raw water turbidity and Power consumption for the Kobe City waterworks.

Although the correlation is not very strong (R^2 = 0.32), a reasonably well-defined relationship between the raw water turbidity and power consumption can be observed. There appears to be a positive linear relationship between the two, suggesting that increase in turbidity levels causes a rise in power consumption. Based on discussions with the utility manager of the Kobe City waterworks, the operating procedure of the utility in response to increased levels of turbidity is to increase the volume of coagulant, and increase the retention time in sedimentation and filtration tanks. It can be inferred that an increased retention time will lead to increased operating hours of the plant since a target volume of water must be supplied irrespective of turbidity. Increased operating hours will naturally mean more power consumption, which is the relationship depicted in Figure 4.6.

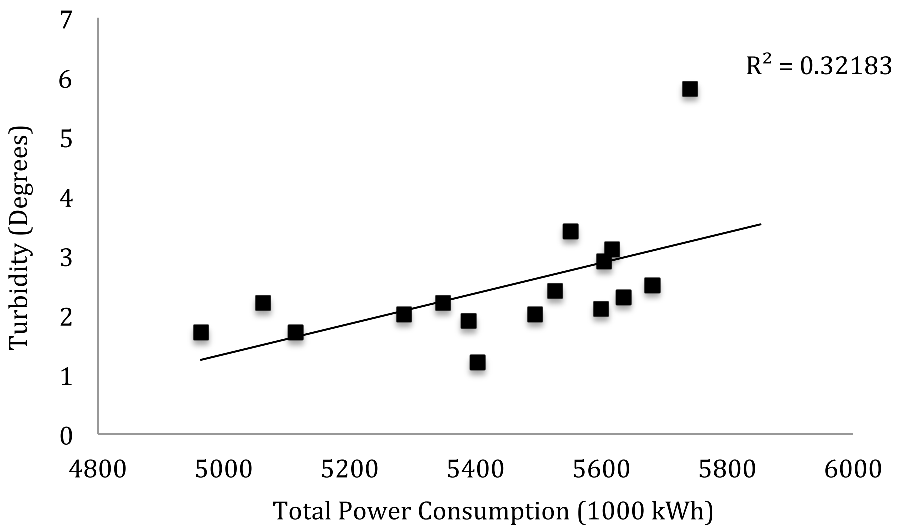


Figure 4.6: Relationship between raw water Turbidity and Power consumption

A total of 16 data exemplars were available to define the Raw water Turbidity-Power consumption relationship, out of which 11 data points were used for developing the models (training) and 5 data points were used for testing the models (testing). Four sets of equations corresponding to Linear, Quadratic, Cubic and Power fits were developed with the training data set, which have been presented in Equations 4.6 through 4.9 respectively.

$P_C = 4933.05 + 230.62\, T_R$……………………………………………………………….(4.6)

$P_C = 5297.10 – 122.57\, T_R + 81.12\, T_R^2$ ……………………………………………………….(4.7)

$P_C = 1.12 \times 10^4 – 9342.73\, T_R + 4593.74\, T_R^2 – 698\, T_R^3$……………………………………….(4.8)

$P_C = 5113.54\, T_R^{0.08}$…………………………………………………………………….(4.9)

Where

P_C: Power Consumption (1000 kWh)

T_R: Turbidity (Degrees)

Figure 4.7 depicts the trend of each model with respect to the training data. It can be observed that the trends for the Linear and Quadratic models are more or less similar within the range 1 – 3 degrees of Turbidity. Although the cubic equation appears to fit the data the best between the range 2 – 2.5 degrees, the trend appears to be cyclic with rounded peaks and troughs, which is inconsistent with the knowledge that the power consumption is likely to increase with higher values of raw water turbidity. The quadratic equation agrees well within the trained data range, but will need to be checked against the testing data set for credibility, while the power equation does not seem valid for low values of turbidity. Table 4.2 presents the results of the Raw water turbidity – Power consumption model for both training and testing sets.

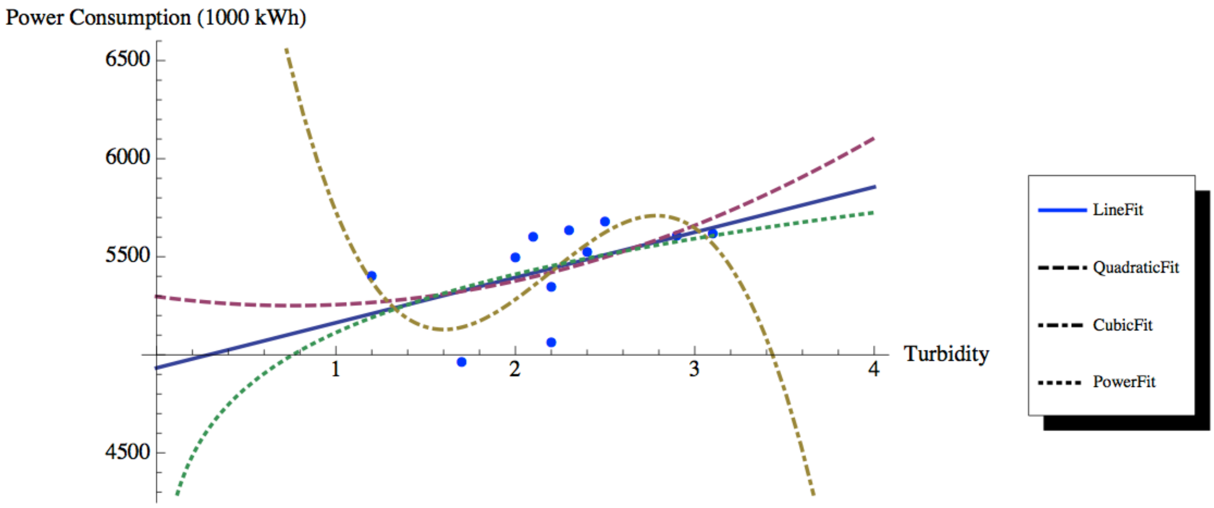


Figure 4.7: Fitted trends for Raw water turbidity – Power consumption models

Table 4.2: Results for Turbidity-Power consumption model

Model 1: Turbidity – Power consumption relationship								
Input: Turbidity (Degrees)								
Output: Power consumption (1000 kWh)								
Training								
Model	Exemplars	AARE	RMSE	Threshold static (%)				
		(%)	(1000 kWh)	0.5 %	1%	2%	5%	10%
Linear	11	2.96	198.27	09.09	27.27	45.45	81.82	100
Quadratic	11	3.03	194.31	09.09	09.09	36.36	81.82	100
Cubic	11	2.51	167.82	0	36.36	54.55	90.91	100
Power	11	3.00	200.56	18.18	27.27	45.45	81.82	100
Testing								
Model	Exemplars	AARE	RMSE	Threshold static (%)				
		(%)	(1000 kWh)	0.5 %	1%	2%	5%	10%
Linear	5	3.74	270.05	20	20	20	80	100
Quadratic	5	7.72	721.50	0	20	40	80	80
Cubic	5	108	13600	40	40	40	60	80
Power	**5**	**2.26**	**142.24**	**20**	**20**	**40**	**100**	**100**

For the training set, it is seen that the cubic equation fits the data the best with a low AARE of 2.51% and an RMSE of 167.82 kWh, while 90.91% of the training set has a relative error of less than 5%. However this model fails miserably with the testing data, where the AARE is 108%. This anomaly is due to a negative value generated for the entry with the largest magnitude in the testing data set. Similarly, the quadratic model fits well with the training data (3.03 % AARE) but not with the testing data (7.72 % AARE) suggesting the unsuitability of this model. Both the Linear and Power models fit the training data well with AARE 2.96% and 3.0% respectively, and 198.27 kWh & 200.56 kWh RMSE respectively, while in both cases 81.82% of the training data has a relative error of less than 5%. However, in the testing data set, the Power model is significantly better than the Linear model with an AARE of 2.26% compared to 3.74%. Moreover, the RMSE of the Power model is also quite low at 142.24kWh, with all testing data points showing a relative error of less than 5%.

Hence, the Power model has been chosen as the best-fit and practical model to depict the relationship between the raw water turbidity and power consumption

$$\textbf{Power Consumption} = \textbf{5113.54 (Raw water turbidity)}^{0.08}$$

Figure 4.8 shows the trend for observed and modeled values of power consumption with the Power model, for the training set where a reasonably good fit is seen. Although the magnitudes of the observed and modeled values do not fit exactly, there is a good fit in terms of the general trend for most part of the data.

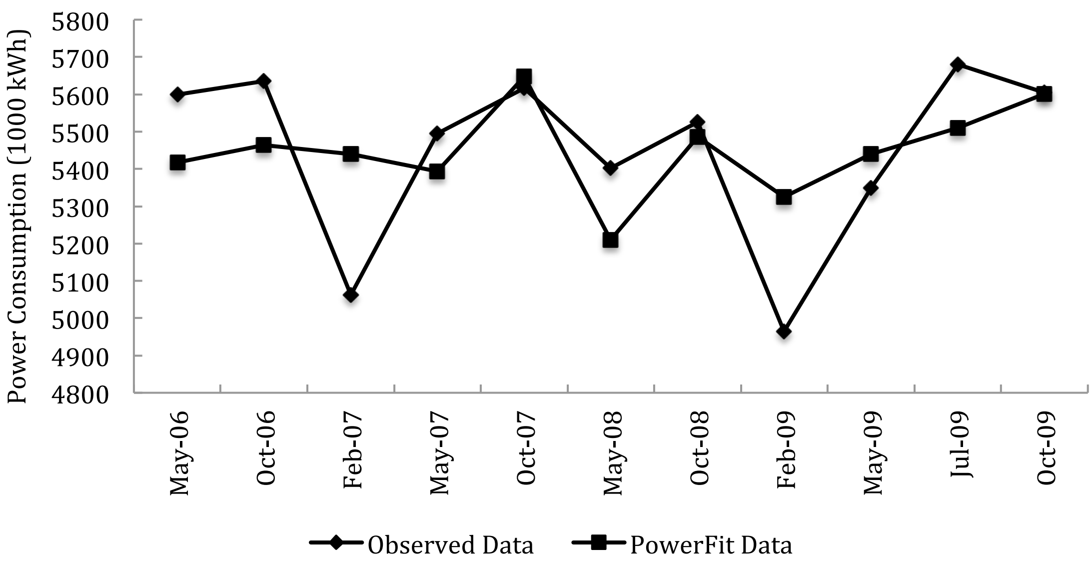


Figure 4.8: Observed and modeled data of Power consumption in training set using power model

The fit is even better for the testing data set shown in Figure 4.9, where the trends for the observed and modeled data appear to match very well. Although the testing data has only five exemplars due to data constraints, a strong correlation can be observed between the observed and modeled values suggesting the suitability of the Power model.

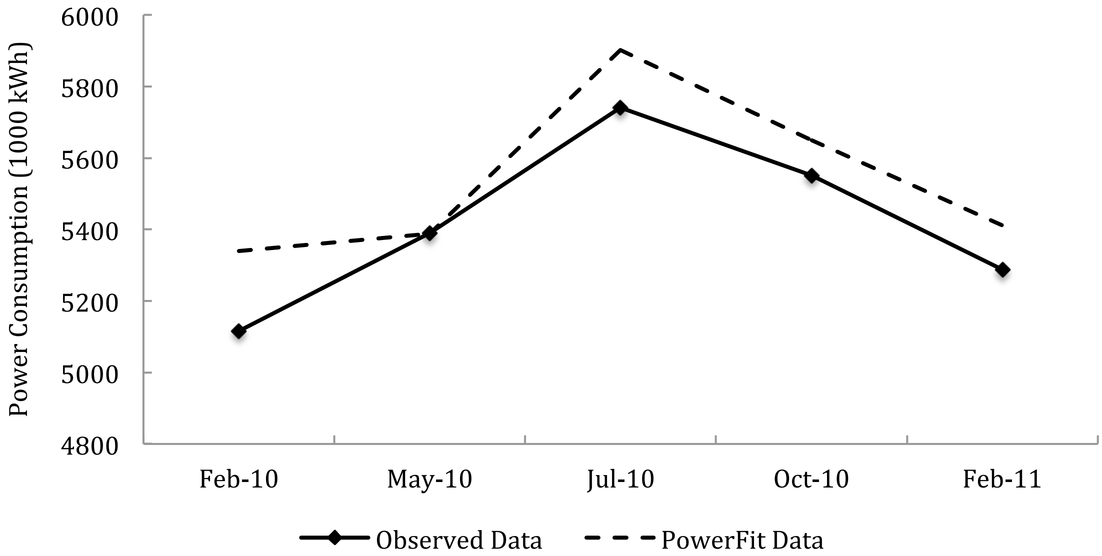


Figure 4.9: Observed and modeled data of Power consumption in testing set using power model

4.6.2 Model 2 (GHG emissions – Power consumption model)

There is an empirical relationship between the GHG emissions and Power consumption. Based on the recommendations made by the Ministry of Environment, Japan emission factors presented in Table 4.3 were used in the study

Table 4.3: Emission factors to calculate GHG emissions from Power consumption

Year	Emission factor
2010	3.11×10^{-4}
2009	2.94×10^{-4}
2008	3.55×10^{-4}
2007	3.66×10^{-4}
2006	3.38×10^{-4}
2005	3.58×10^{-4}

The emission factors should be multiplied with the Power consumption (in kWh) to obtain the GHG emissions as tones of $C0_2$.

4.6.3 Model 3 (Power consumption – Water production volume model)

The purpose of developing this model was to relate the Power consumption of the Kobe City waterworks to the volume of water produced, which would be then used to evaluate some selected PIs of the 9-cPIS. Figure 4.10 shows the trend of water production volume with respect to Power consumption. It can be seen that there is a very strong linear relationship between the two (R^2 = 0.82), which is logically sound since the volume of water supplied is expected to be proportional to the power consumption, especially so in Kobe City waterworks where electricity is the only source of energy used in every stage of water production.

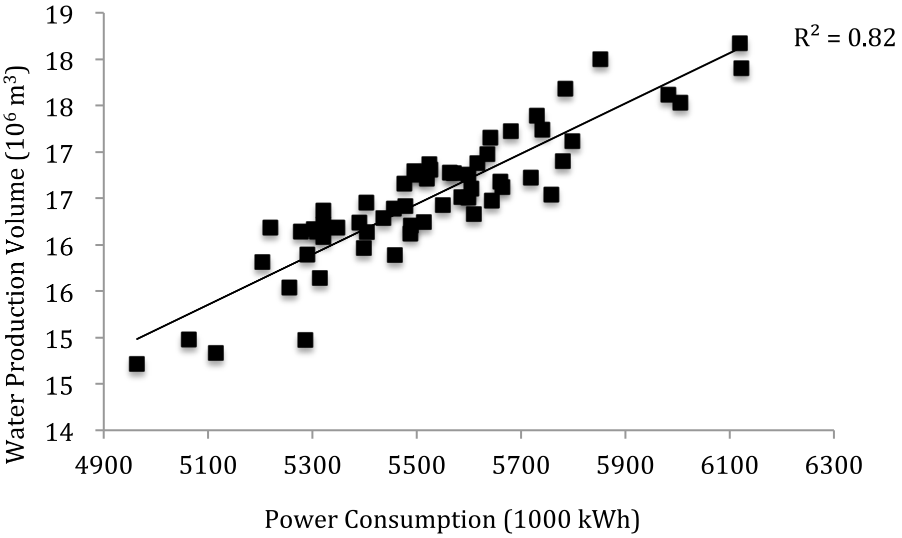


Figure 4.10: Relationship between Water production volume and Power consumption

A total of 60 data exemplars were available to define the Power consumption-Water production volume relationship, out of which 40 data points were used for developing the models (training) and 20 data points were used for testing the models (testing). The four models corresponding to Linear, Quadratic, Cubic and Power fits are expressed in equations 4.10 through 4.13

$W_p = 1.75 + 2.68 \times 10^{-3} P_C$……………………………………………………………………………(4.10)

$W_p = -22.02 + 1.12 \times 10^{-2} P_C - 7.69 \times 10^{-7} P_C^2$…………………………………………………………(4.11)

$W_p = -241.72 + 0.13 P_C - 2.22 \times 10^{-5} P_C^2 + 1.28 \times 10^{-9} P_C^3$……………………………………………(4.12)

$W_p = 7.59 P_C^{0.89}$……………………………………………………………………………………(4.13)

Where P_C: Power Consumption (1000 kWh)

W_P: Water production volume (10^6 m^3)

Figure 4.11 depicts the trends of the four models against the observed training data, where it is clear that all the models fit the observed data quite well within the range 5000 to 6500 x 10^3 kWh, although the Cubic and Quadratic models may not necessarily follow the same trend outside the range 5 Million – 6.2 Million kWh. Hence for all practical purposes the linear and power models appear to be better choices.

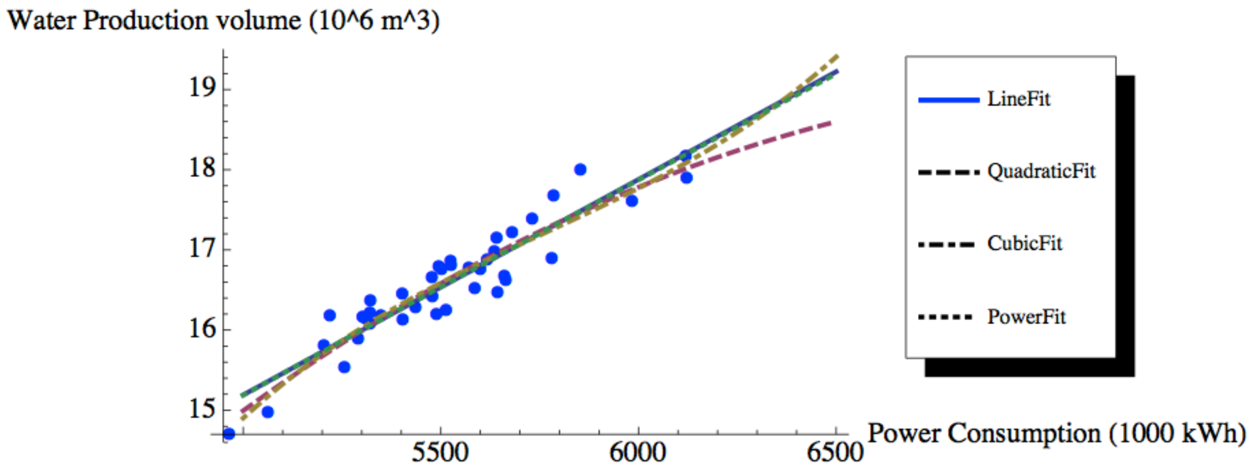


Figure 4.11: Fitted trends for Power consumption – Water production volume models

Table 4.4 presents the statistical results of the four Power consumption-Water production volume models, for both the training and testing sets.

Table 4.4: Results for Power consumption – Water production volume model

Model 3: Power consumption – Water production volume relationship								
Input: Power consumption (1000 kWh) Output: Water production volume (10^6 m^3)								
Training								
Model	Exemplars	AARE	RMSE	Threshold static (%)				
		(%)	(10^6 m^3)	0.5 %	1%	2%	5%	10%
Linear	40	1.33	0.256	27.50	32.50	77.50	100	100
Quadratic	40	1.24	0.228	15	45	77.50	100	100
Cubic	40	1.20	0.243	20	50	77.50	100	100
Power	40	1.33	0.240	27.50	32.50	75	100	100
Testing								
Model	Exemplars	AARE	RMSE	Threshold static (%)				
		(%)	(10^6 m^3)	0.5 %	1%	2%	5%	10%
Linear	20	2.09	0.413	20	25	55	95	100
Quadratic	20	2.12	0.417	25	25	50	95	100
Cubic	20	2.11	0.415	20	25	55	95	100
Power	20	2.09	0.414	20	25	55	95	100

In the training set, yet again the cubic model appears to fit the data best with an AARE of 1.20%, RMSE 0.243 x 10^6 m^3, and all data exemplars show a relative error of less than 5%. There is not much difference among the other models, wherein all data exemplars have a relative error of less than 5%, with low AARE (1.24 % for Quadratic and 1.33% for Linear and Power models). Further, the RMSE for all models range between 0.228 and 0.256 Million cubic meters, which is a small range.

Similar results are seen for the testing set as well, where AARE for all models lies in the range 2.09 to 2.12 %. Also, the RMSE for the models is quite similar in the range 0.413 to 0.417 x 10^6 m^3, and 95% of the data set, in all four cases, display a relative error of less than 5%. Hence, it can be said that all the models are more or less identical. However as indicated earlier, the cubic and quadratic models may not show the same trend for different ranges of input, especially when the input range is beyond the range trained and tested in the study. Hence, the choice is between the linear and power models. Among the two, the linear model has a lower RMSE (0.413 Million m^3 compared to 0.414 Million m^3) and hence has been chosen as the best-fit model.

Water production volume = 1.75 + 2.68 x 10 $^{-3}$ Power Consumption

Figure 4.12 shows the trends of observed and modeled data of Water production volume with the linear model, for the training set where a near perfect match can be observed. This is due to the high correlation between the two variables. The observed and modeled data in the testing data set, seen in Figure 4.13, is not quite as good as the training set but yet indicates a decent match. Hence, for all practical purposes it appears that the linear model is suitable to depict the relationship between the water production and power consumption.

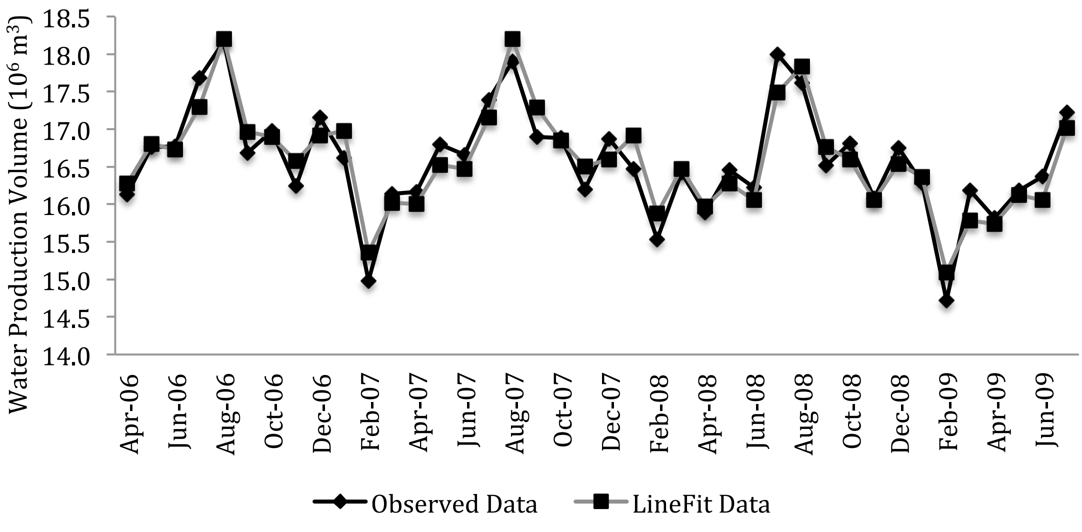


Figure 4.12: Observed and modeled data of Water production volume in training set using linear model

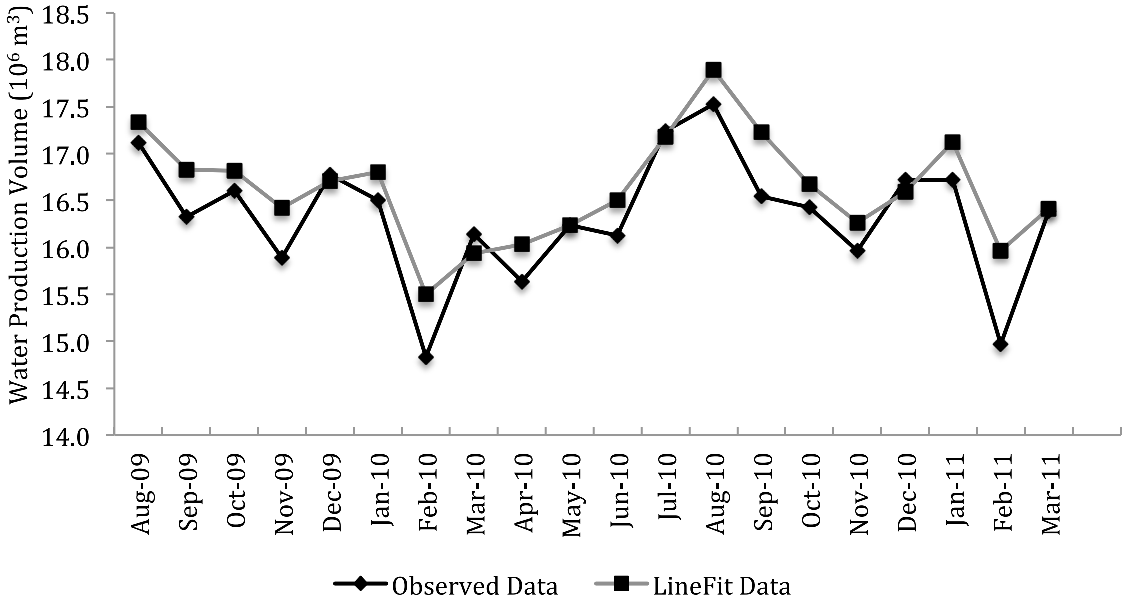


Figure 4.13: Observed and modeled data of Water production volume in testing set using linear model

4.6.4 Model 4 (Water production volume – Financial Sustainability model)

Financial Sustainability is one of the components of the 9-cPIS. As highlighted earlier in Chapter 2, there are four contributing variables to Financial Sustainability – Current account balance ratio, Total balance ratio, Revenue to cost ratio of water supply and Operating balance ratio. The details of the regression equations and explanatory variables can be revisited in section 2.7.4.

The objective of this model was to establish a relationship between the Water production volume and the Financial Sustainability PI. By understanding this relationship, it will then be possible to estimate the affect of change in the water production volume, under scenarios of climate and socioeconomic change, on the Financial Sustainability Indicator. By using this relationship, and scenarios of expected change, the Kobe City waterworks will be able to assess the impact of change in production on the Financial Sustainability of the utility.

Figure 4.14 shows the preliminary relationship between water production volume and Financial Sustainability of Kobe City Waterworks. There appears to be a reasonably strong negative linear relationship between the two (R^2 = 0.54) suggesting that with an increase in water production volume, the Financial Sustainability decreases. This is because, for the Kobe City waterworks, the unit cost of producing water is greater than the unit-selling price of water. Hence with increased production, the revenue losses increase, leading to reduced Financial Sustainability.

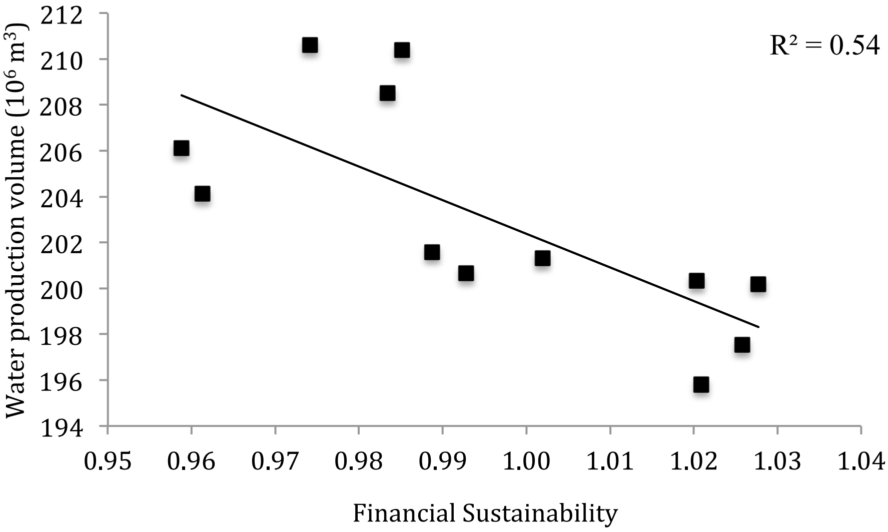


Figure 4.14: Relationship between Water production volume and Financial Sustainability

12 data exemplars were available for the analysis. In this case all the data was used for model development without division into training and testing sets. This is because the ultimate aim of developing this relationship is not to get an accurate value of the Financial Sustainability under different scenarios, but rather to make a relative comparison of the values under different scenarios to help the utility in decision-making. The four models corresponding to Linear, Quadratic, Cubic and Power fits are expressed in equations 4.14 through 4.17, whereas the trends of the four models are shown in Figure 4.15

$$FS = 2.07 - 5.34 \times 10^{-3} W_P \qquad (4.14)$$
$$FS = 9.38 - 7.70 \times 10^{-2} W_P + 1.76 \times 10^{-4} W_P^2 \qquad (4.15)$$
$$FS = -1073.11 + 15.93 W_P - 7.87 \times 10^{-2} W_P^2 + 1.30 \times 10^{-4} W_P^3 \qquad (4.16)$$
$$FS = 72.16 W_P^{-0.81} \qquad (4.17)$$

Where,

FS: Financial Sustainability

W_P: Water production volume (10^6 m^3)

Figure 4.15 depicts the trends of the four models, while Table 4.5 presents the statistical results of the four Water production volume –Financial sustainability models, where it is seen that the cubic model provides the least AARE (1.72%). However, the cubic model is cyclic in nature as seen in Figure 4.15, and thus not suitable. Among the other there models, the quadratic model has the least error but, given its trend, it cannot be considered since it is not likely that the model will work outside the range 196 – 210 x 10^6 m^3 of water production volume. Both the power and the linear model can be considered for the modeling because the AARE is nearly identical in both cases, and in both cases 92.31% of the data has a relative error of less than 5%.

The linear model was chosen as the best-fit model due to its simpler structure.

Financial Sustainability = 2.07 – 5.34 x 10^{-3} Water production volume

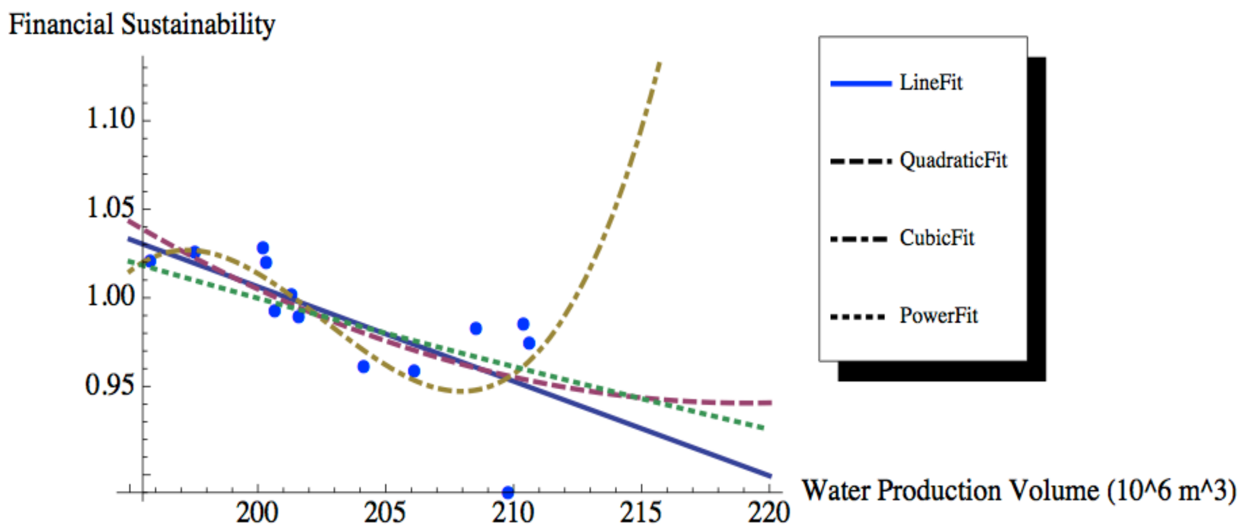


Figure 4.15: Fitted trends for Water production volume – Financial Sustainability models

Table 4.5: Results for Water production volume-Financial Sustainability model

Model 4: Water production volume – Financial Sustainability relationship							
Input: Water production volume (10^6 m^3)							
Output: Financial Sustainability							
Model	Exemplars	AARE	Threshold static (%)				
		(%)	0.5 %	1%	2%	5%	10%
Linear	13	2.06	07.69	30.77	53.85	92.31	100
Quadratic	13	2.00	07.69	30.77	61.54	92.31	100
Cubic	13	1.72	23.08	53.85	76.92	92.31	100
Power	13	2.04	23.08	30.77	61.54	92.31	100

Figure 4.16 depicts the observed and modeled data for Financial Sustainability using the linear model. For most part of the course the two trends are similar except in the tail part where there appears to be some discrepancy. However, as mentioned earlier since the objective is to make a relative comparison of the Financial Sustainability under different scenarios, the slight discrepancies may not be very significant.

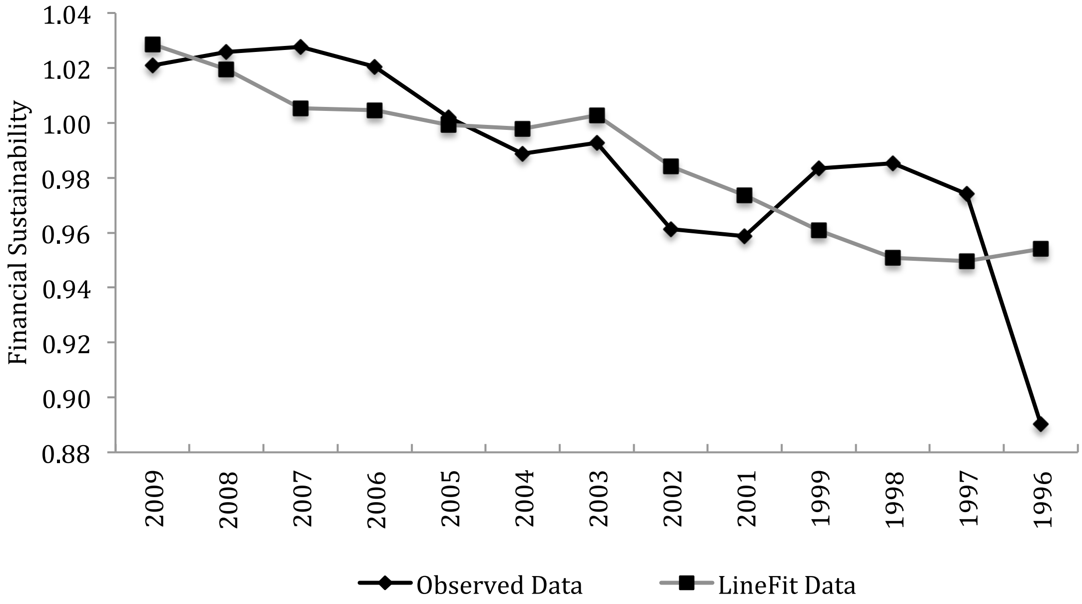


Figure 4.16: Observed and modeled data for Financial Sustainability using linear model

4.6.5 Model 5 (Water production volume – Green Water Supply model)

Green Water Supply (GWS) is an integral component of the 9-cPIS, especially in light of providing an environmentally friendly supply. There are three main variables in this component – Greenhouse gases emissions, Power consumption and Energy consumption. In Kobe City waterworks, the only source of energy used for all purposes, except vehicle fuel, is electricity. Hence, the GWS in this context will only include the GHG emissions and power consumption. Section 2.7.4 can be referred to for details of the regression equation for GWS. Figure 4.17 shows the relationship between the water production volume and the GWS.

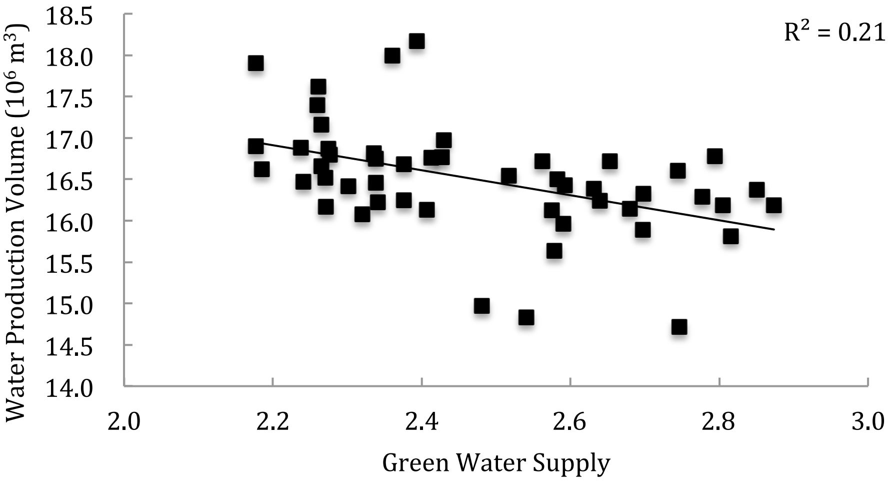


Figure 4.17: Relationship between Water production volume and Green Water Supply

There does not seem to be a very well defined relationship between the two, which is also exemplified by the low coefficient of determination (R^2 = 0.21). However, the general trend is that as the water production volume decreases, the GWS increases. This agrees very well with the field condition because a reduction in water production volume leads to lower power consumption (already seen in section 4.6.3), and lower power consumption generate lower GHG emissions (already seen in section 4.6.2).

50 data exemplars were used for the model development and the four models corresponding to Linear, Quadratic, Cubic and Power fits are expressed in equations 4.18 through 4.21, whereas the trends of the four models are shown in Figure 4.18.

$GWS = 4.78 - 0.14\ W_P$……………………………………………………………………...........….(4.18)

$GWS = 0.55 + 0.38\ W_P - 1.5 \times 10^{-2}\ W_P^2$………………………………………………..……….(4.19)

$GWS = -332.91 + 61.57\ W_P - 3.75\ W_P^2 + 7.57 \times 10^{-2}\ W_P^3$…………………………………..….(4.20)

$GWS = 30.85\ W_P^{0.90}$……………………………………………………………………..…(4.21)

Where,

GWS: Green Water Supply

W_P: Water production volume (10^6 m^3)

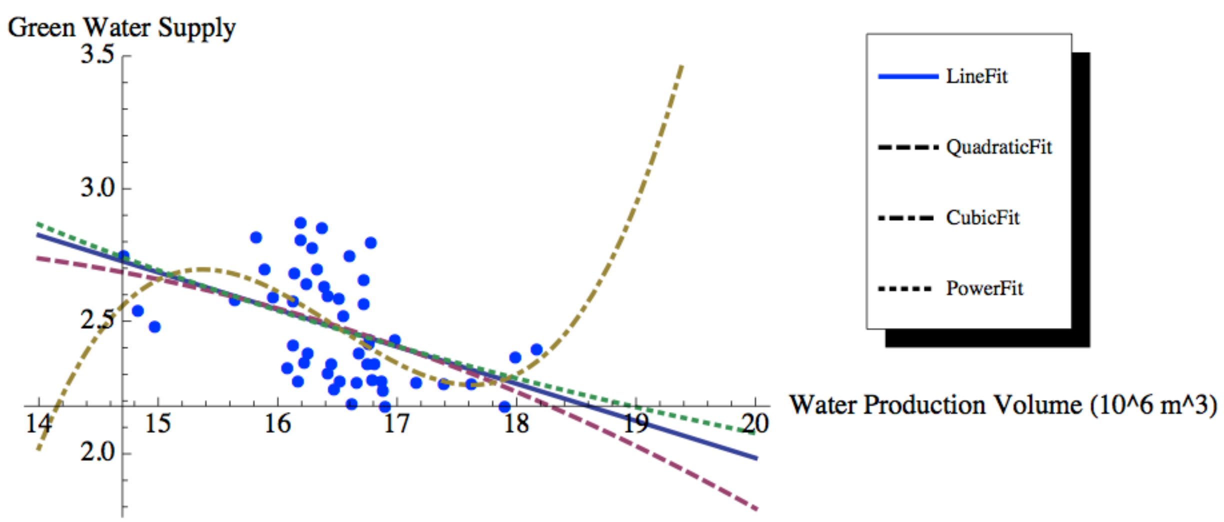


Figure 4.18: Fitted trends for Water production volume – Green Water Supply models

Table 4.6 presents the results of the Water production volume – Green Water Supply models, and it is observed that the AARE of all models is relatively high compared to the previous models. This is probably because of the weak relationship between the two, as indicated earlier. The cubic model is not suitable because of the cyclic trend, in spite of its low AARE (5.82%). There is very little difference between the linear, quadratic and power models in terms of AARE, and in all cases more than 80% of the data show a relative error of less than 10%.

To maintain a simple structure, the linear model was chosen as the best-fit model

Green Water Supply = 4.78 – 0.14 Water production volume

Table 4.6: Results for Water production volume-Green Water Supply model

Model 6: Water production volume – Green Water Supply relationship							
Input: Water production volume (10^6 m^3) Output: Green Water Supply							
Model	Exemplars	AARE (%)	Threshold static (%) 0.5 %	1%	2%	5%	10%
Linear	50	6.27	4	8	10	36	80
Quadratic	50	6.29	4	10	14	46	84
Cubic	50	5.82	2	6	12	42	82
Power	50	6.28	4	8	10	38	80

The trend for the observed and modeled demand of GWS, with the linear model is shown in Figure 4.19. Inspite of the relatively higher AARE of the model, there appears to be a very good fit between the two data suggesting the suitability of this model for further analysis.

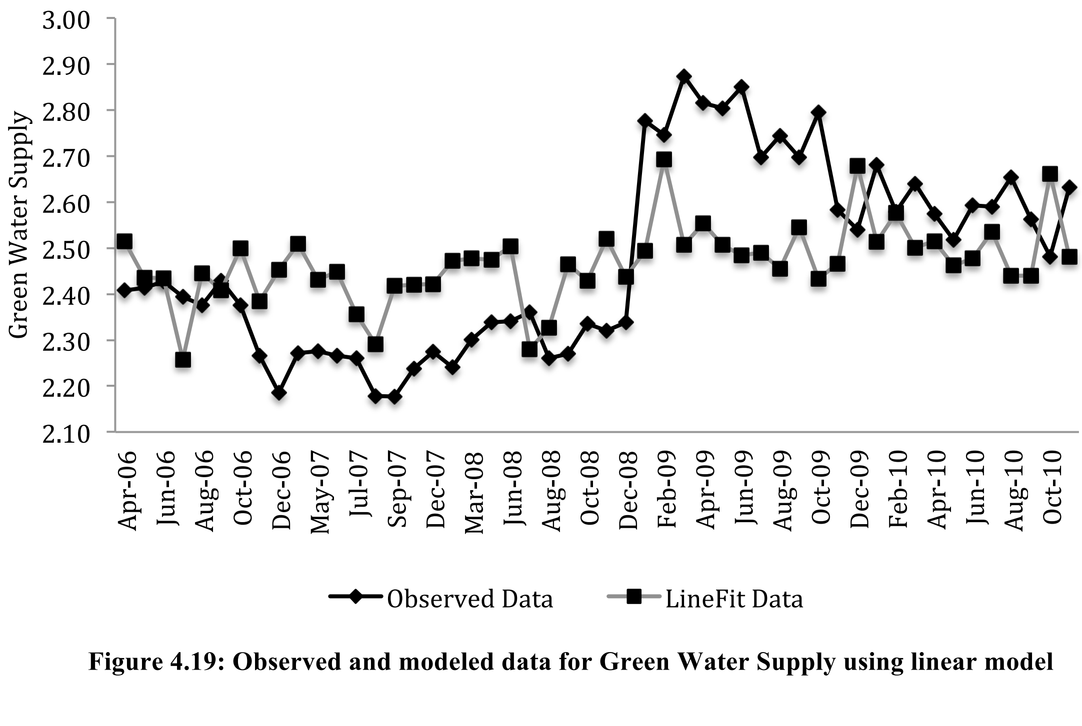


Figure 4.19: Observed and modeled data for Green Water Supply using linear model

4.6.6 Model 6 (Water production volume – Economic Value of Water model)

The Economic Value of Water (EV) indicator of the 9-cPIS deals with the water charges and fees for various scales of supply. It has four main variables – Water supply revenue, Price of water for households using up to 20 m^3/month, Water production cost and Price of water for households using up to 10 m^3/month. Figure 4.20 shows the relationship between the volume of water production and the EV. As expected, there seems to be quite a strong correlation between the two variables, which is exemplified by a high value of the coefficient of determination (R^2 = 0.76).

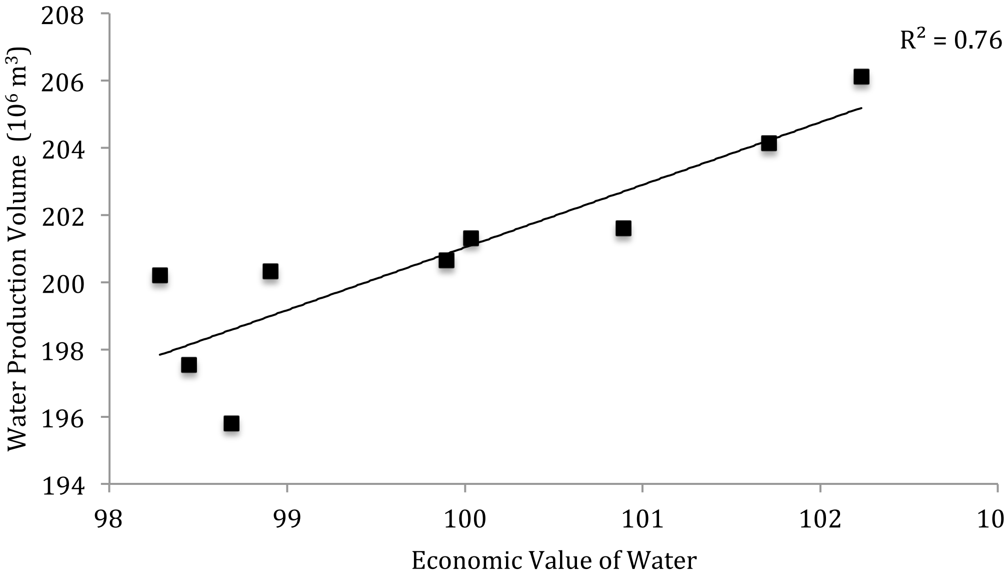


Figure 4.20: Relationship between Water production volume and Economic Value of Water

9 data exemplars were used to establish the relationship between the Water production volume and Economic value of Water. The four models corresponding to Linear, Quadratic, Cubic and Power fits are expressed in equations 4.22 through 4.25, whereas the trends of the four models are shown in Figure 4.21.

$EV = 17.06 + 0.41\ W_P$ ……………………………………………………………………..….(4.22)

$EV = 1241.93 – 11.78\ W_P + 0.30 \times 10^{-2}\ W_P^2$ ……………………………………………………….(4.23)

$EV = 1.38 \times 10^5 – 2054.55\ W_P + 10.20\ W_P^2 – 0.02\ W_P^3$ …………………………………..……….(4.24)

$EV = 1.22\ W_P^{0.93}$ ………………..…………………………………………………………..…(4.25)

Where,

EV = Economic Value of Water

W_P = Water production volume (10^6 m^3)

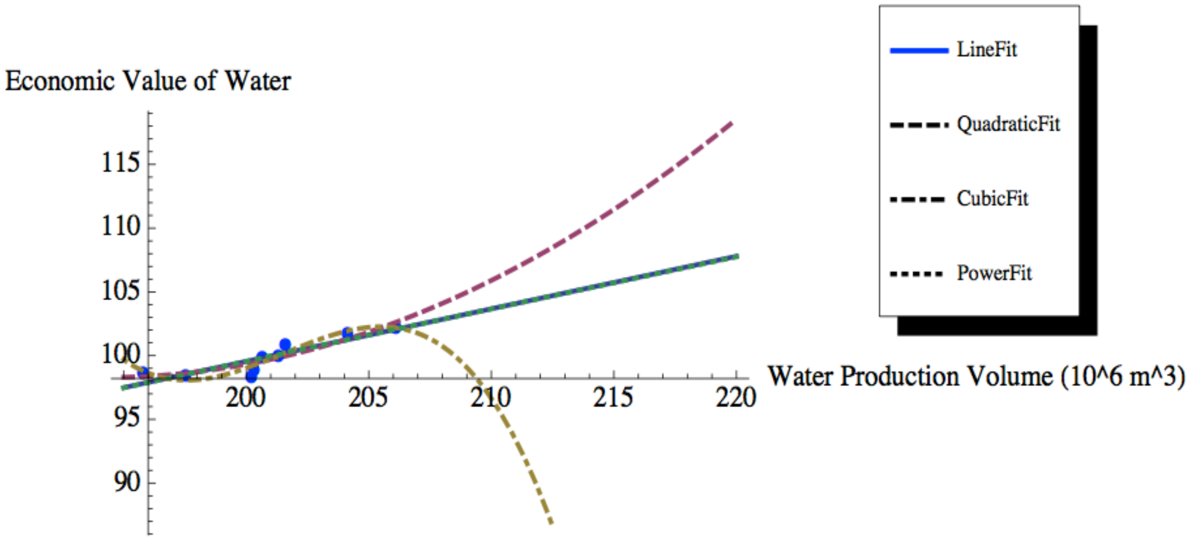


Figure 4.21: Fitted trends for Water production volume – Economic Value of Water models

Table 4.7 presents the results of the Water production volume – Economic Value of water models, where it is seen that yet again the cubic model provides the least AARE (0.35%). This model can be very useful if the water production volume ranges between 196 and 206 x 10^6 m^3. However, under climate and socioeconomic change it is difficult to restrict the water production volume to this range. Among the other models, there is not much difference in terms of AARE (0.49% and 0.51%) and the threshold static, with the relative error less than 2% for all exemplars for all models. Hence, for simplicity the linear model was chosen for subsequent analysis

Economic Value of Water = 17.06 + 0.41 Water production Volume

Table 4.7: Results for Water production volume-Economic Value of Water model

Model 5: Water production volume – Economic Value of Water relationship							
Input: Water production volume (10^6 m^3)							
Output: Economic Value of Water							
Model	Exemplars	AARE	Threshold static (%)				
		(%)	0.5 %	1%	2%	5%	10%
Linear	9	0.51	55.56	88.89	100	100	100
Quadratic	9	0.49	66.67	88.89	100	100	100
Cubic	9	0.35	77.78	100	100	100	100
Power	9	0.51	55.56	88.89	100	100	100

The trend for the observed and modeled data for Economic Value of Water using the linear model is shown in Figure 4.22. The data appear to fit quite well suggesting the suitability of the model.

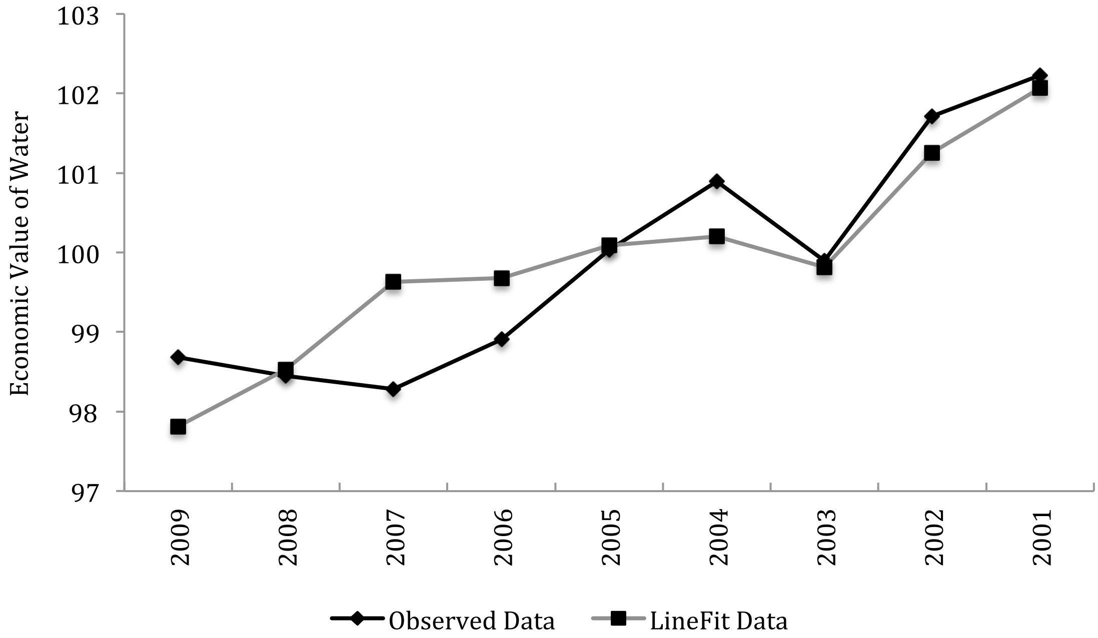


Figure 4.22: Observed and modeled data for Economic Value of water using linear model

4.7 Summary

The thematic objective of this chapter was to develop regression models between selected variables. Two independent variables were chosen – Raw water turbidity and GHG emissions. The variables were chosen because they are likely to be influenced by the climate change phenomenon. The two dependent variables selected, Power consumption and Water production volume, were chosen because of their strong relationship with the selected performance indicators of the 9-cPIS, namely Financial Sustainability, Green Water Supply and Economic Value of Water. Six univariate models were developed: Raw water turbidity – Power consumption model, GHG emissions – Power consumption model, Power consumption – Water production volume model, Water production volume – Financial Sustainability model, Water production volume – Green Water Supply model and Water production volume – Economic Value of Water model. Each model was tested against three statistical indices – AARE, RMSE and Threshold static. All the models were developed with data obtained from the Kobe City Waterworks, Japan, the water utility used for this test study. The models developed in this chapter will now be subsequently tested against different scenarios of climate change in the subsequent chapter.

CHAPTER V

DEVELOPING TRADEOFF BETWEEN CONSUMER EXPECTATIONS OF WATER QUALITY AND ENERGY REDUCTION

5.1 Thematic objective

Climate change is likely to cause a change in raw water quality because of which production of safe and reliable tap water is an eminent concern. Additionally, consumers are becoming more health conscious as a wealth of information is being made available to them, and their expectations of tap water quality have increased dramatically, especially with advent in technology. To meet consumer expectations, adopting advanced water treatment is an option but doing so will result in increased energy consumption because these treatments are energy intensive. Given that utilities should make every effort possible to reduce their GHG emissions, in order to combat the effects of climate change, switching to advanced treatments may not be advisable. Hence, the challenge for utilities is to arrive at a feasible tradeoff between meeting the consumer expectations and reduction in energy use. This objective of this chapter is to design the appropriate tradeoff using numerical modeling.

In the previous chapter six regression models were developed using the variables likely to be affected by climate change (raw water turbidity and GHG emissions) as independent variables, and the power consumption and water production volume as dependent variables, for Kobe City Waterworks. Relationships were then established between the water production volume and selected components of the 9-cPIS (Financial sustainability, Green water supply and Economic Value of water). In this chapter the regression models have been evaluated under different scenarios of climate change. Then, based on the evaluation results, tradeoffs between consumer expectations of water quality and reduction in GHG emissions for various scenarios have been developed.

5.2 Scenarios of change

This study considers two major phenomenon of change – Change in raw water quality and Reduction in GHG emissions. While the scenarios of change in raw water turbidity due to climate change encourage the utility to prepare for adaptation, scenarios of reduction in GHG emissions support mitigation efforts. Both adaptation and mitigation are important processes to address the ill effects of climate change. The IPCC defines mitigation as "an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases" (GHG), which are responsible for climate change, whereas adaptation is an "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2001 a).

5.2.1 Scenarios of changes in Raw water turbidity

As described previously in Chapter 4, in a survey conducted with major water utilities in Japan by the JWRC in 2008, a majority of the utilities indicated that the effect of short-term weather changes, like heavy rainfall, is most often a rise in the raw water turbidity parameter. Because climate change is expected to cause wetter days in Japan (MLITT, 2008), the raw water turbidity is an important driver of change. Figure 5.1 shows the time series trend for raw water turbidity of the Senghari treatment plant of the Kobe City Waterworks for six years (2005-2010). The median value of raw water turbidity data is around 2.15 Degrees, with most values below 5 Degrees. A maximum value of 24 degrees was observed in July 2006, possibly due to an extreme rainfall event.

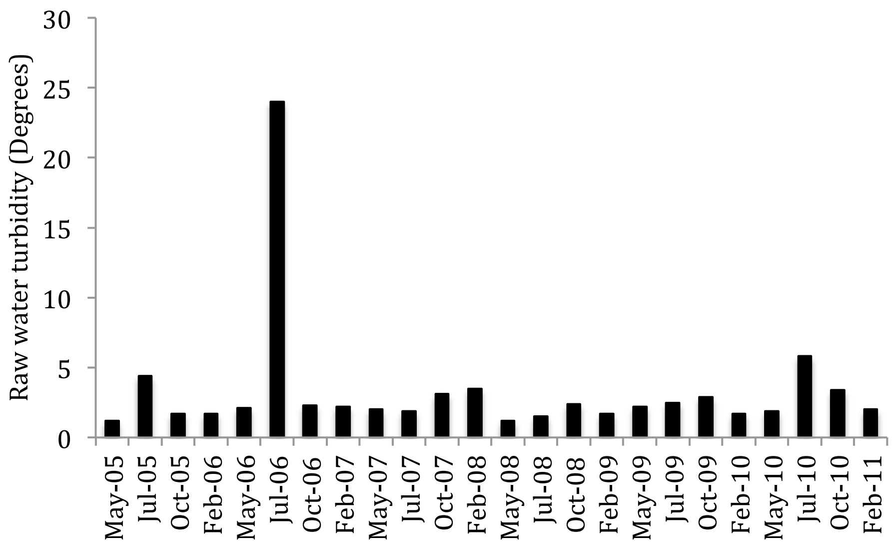


Figure 5.1: Trend of raw water turbidity in Senghari treatment plant between 2005 and 2010

Based on historical data, it appears that the changes in raw water turbidity have never been sudden except when an extreme rainfall event occurs. Even then, high turbidity values are observed for a short time only. Hence from a utility point of view, steady but consistent rise in raw water turbidity is more significant than a sudden extreme increase. While the former will require a change in treatment technology and mode of operation, the latter can be addressed by merely shutting down intake temporarily, if enough storage is available.

Hence, most of the scenarios considered for this module are steady but consistent increase in raw water turbidity. The average monthly raw water turbidity for the year 2010 has been considered as the base condition, and scenarios have been generated with percentage increments from the base condition. Only one scenario has been considered for an extreme event, where the raw water turbidity was hypothesized to reach 100 Degrees, based on actual projections for Japan made by the Federation of Japan Water Industries (2010). Table 5.1 presents the various scenarios for raw water turbidity considered in the study.

Table 5.1: Scenarios for increase in raw water Turbidity

	Condition	Expected raw water turbidity (Degrees)
BC_{TUR}	Base condition	3.275
TUR_{5}	5% increase in Turbidity	3.439
TUR_{10}	10% increase in Turbidity	3.602
TUR_{15}	15% increase in Turbidity	3.766
TUR_{20}	20% increase in Turbidity	3.930
TUR_{25}	25% increase in Turbidity	4.094
TUR_{50}	50% increase in Turbidity	4.912
TUR_{100}	100% increase in Turbidity	6.550
TUR_{150}	150% increase in Turbidity	8.8.18
TUR_{MAX}	Max increase in Turbidity	100

As stated earlier, one of the effects of climate change in Japan is a likely increase in rainfall volume and intensity. Hence, ideally it may be more effective if a relationship could be established between the rainfall and raw water turbidity, since usually with more rainfall the sediment transport in rivers would increase. If the aforementioned relationship is known, then the scenarios of raw water turbidity can be generated for various magnitudes of rainfall, instead of regular percentage increments of raw water turbidity.

To explore this relationship, monthly rainfall data was obtained from Meteorological station 47770, Kobe, which is very close to the intake source for the Senghari water treatment plant. The relationship between rainfall and raw turbidity is depicted in Figure 5.2. It can be observed that there is no discernable relationship between the two, with a very low coefficient of determination (0.15). This suggests that the raw water turbidity in the area may also depend upon additional factors like soil type, land use, topography etc., and not just the rainfall. Hence, it is not possible to model the rainfall-turbidity relationship univariately. It might be possible to model the relationship between the two variables using multivariate analysis but due to time and resource constraints it was not possible to do so in this study. Under the circumstances, the original regular percentage increments of raw water turbidity were continued with for this module.

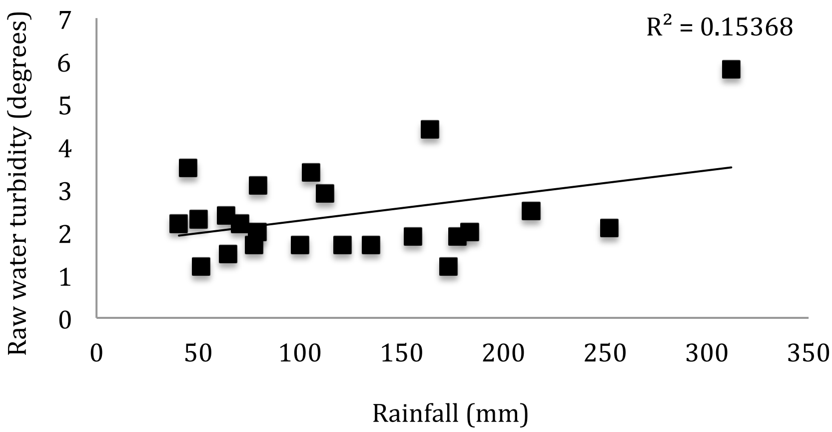


Figure 5.2: Monthly rainfall – raw water turbidity relationship for Senghari treatment plant

5.2.2 Scenarios of reduction in GHG emissions

Given that Japan is committed to reduce its GHG emissions by 25% up to the year 2020, the scenarios used in this study considered increments in percentage reduction from the 2010 base year. Table 5.2 presents the various scenarios used in the study, where the target power consumption and GHG emissions have been established based on the Power consumption-GHG emissions model (Model-2) developed earlier in Chapter 4.

Table 5.2: Scenarios for reduction of GHG emissions

Code	Condition	Target Power consumption (kWh)	Target GHG emissions ($t\text{-}CO_2$)
BC_{GHG}	Base condition	5.55×10^6	1726.737
GHG_5	5% reduction in GHG emissions	5.27×10^6	1640.400
GHG_{10}	10% reduction in GHG emissions	5.00×10^6	1554.063
GHG_{15}	15% reduction in GHG emissions	4.72×10^6	1467.727
GHG_{20}	20% reduction in GHG emissions	4.44×10^6	1381.390
GHG_{25}	25% reduction in GHG emissions	4.16×10^6	1295.053

5.3 Research methodology

Figure 5.3 elucidates the step-by-step methodology used in the study. The methodology is based on performing Monte Carlo simulations on the input data set to arrive at the most probable value of the output, with a certain degree of confidence. Details of the theory, application and advantages of Monte Carlo simulations are explained in the next section.

Example: Turbidity – Power Consumption model
Input: Turbidity
Output: Power Consumption

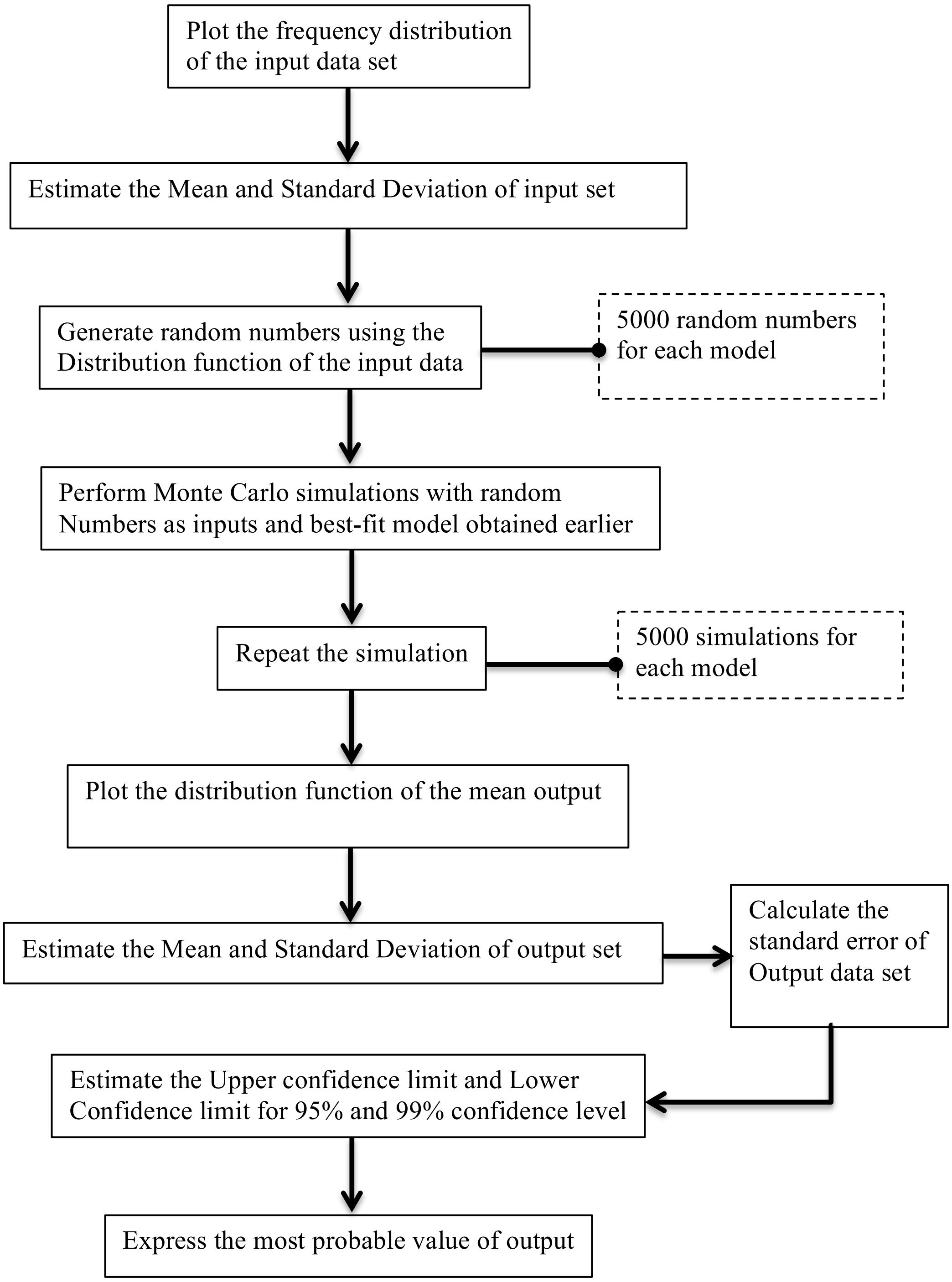


Figure 5.3: Schematic for numerical simulation

Monte Carlo simulations were performed with the six regression models developed earlier in Chapter 4: Raw water turbidity – Power consumption, GHG emissions – Power consumption, Power consumption –

Water production volume, Water production volume – Financial Sustainability, Water production volume – Green Water Supply and Water production volume – Economic Value of Water. The first term in each model corresponds to the input while the second term is the output. The analysis was performed with Wolfram Mathematica 8 software. To begin with, the frequency distribution of the input for each model was plotted, based on historical data. Depending on the shape of the distribution, the distribution function of the input was estimated. ***All the model inputs in the study were found to be more or less normally distributed.***

Next, by using the values of the mean and the standard deviation of the input data set in the distribution function, 5000 random values of the input were generated. Then, by applying the relationships developed in the regression models (Chapter 4), the output corresponding to each random value was calculated. This resulted in 5000 values of the output. In the next stage, the mean value of all the outputs was calculated and recorded.

The same procedure was repeated 5000 times (5000 simulations or iterations) with different sets of 5000 random values, thereby generating 5000 mean (average) values of the output. The frequency distribution of the output, using the 5000 mean values, was then plotted. Based on the shape of the distribution, the most probable value of the output was estimated. Because in most cases the output distribution resembled a normal distribution, the average value of the output was used as the most probable value. To test this value for confidence, 2 confidence levels were used – 95% and 99%. The standard error of the output distribution was calculated using equation 5.1, while the lower and upper confidence limits for each confidence level were calculated using equations 5.2 and 5.3.

$$S_E = \frac{s}{\sqrt{n}} \quad \text{……………………………………(5.1)}$$

$$UCL = Mean + z.\ S_E \quad \text{……………………………………(5.2)}$$

$$LCL = Mean - z.\ S_E \quad \text{……………………………………(5.3)}$$

Where,

S_E = Standard Error

s = Standard deviation

n = Sample size

UCL = Upper confidence limit

LCL = Lower confidence limit

z = z value = 1.96 for 95% confidence and 2.575 for 99% confidence

5.4 Monte Carlo Simulation

5.4.1 General

Monte Carlo simulation is a technique that uses random numbers and probability to solve problems, under conditions of uncertainty. John von Neumann, Stanislaw Ulam and Nicholas Metropolis coined the Monte Carlo method in the 1940s, while they were working on nuclear weapon projects (Manhattan Project) in the Los Alamos National Laboratory. With Monte Carlo simulations, the analysis is performed by substituting a range of random values – a probability distribution – for any factor that has some uncertainty. The results are then calculated over and over again, each time using a different set of random values from the probability function. Depending upon the number of uncertainties and the ranges specified for them, a Monte Carlo simulation could involve thousands or tens of thousands of recalculations before it is complete. The output of Monte Carlo simulations is in the form of distributions of possible outcome values. Using the correct probability distribution function is crucial in determining realistic outcomes. There are a number of distribution functions, some of which are mentioned hereafter.

5.4.2 Common Distribution functions

Normal – Or "bell curve": This is the most common type of distribution where values in the middle near the mean are most likely to occur. Normal distributions are symmetrical with a single central peak at the mean (average) of the data. The shape of the curve is described as bell-shaped with the graph falling off evenly on either side of the mean. Fifty percent of the distribution lies to the left of the mean and fifty percent lies to the right of the mean. The spread of a normal distribution is controlled by the standard deviation. The smaller the standard deviation the more concentrated the data.

The general formula for the probability density function of the normal distribution is described in equation 5.4

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/(2\sigma^2)}$$

……………………………………………………………………………..(5.4)

where,

μ = mean of the variate x and σ^2 = variance

By taking $\mu = 0$ and $\sigma^2 = 1$ in Equation 5.4, the standard normal distribution function is obtained.

Lognormal: Values are positively skewed, not symmetric like a normal distribution. The logarithm of the variable is normally distributed. It is used to represent values that are greater than zero, with unlimited positive potential. The general formula for the probability density function of the lognormal distribution is described in equation 5.5

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(\ln x - \mu)^2/(2\sigma^2)} \quad \text{……………………………………………………………………..(5.5)}$$

Uniform: All values have an equal chance of occurring.

Triangular: It is a continuous probability distribution with a lower limit, upper limit and a mode (most likely value). Values around the mode are more likely to occur. The general formula for the probability density function of the triangular distribution is described in equations 5.6a and 5.6b.

$$P(x) = \frac{2(x-a)}{(b-a)(c-a)} \quad \text{For } a \le x \le c \text{ ……………………………………………………..……….(5.6a)}$$

$$P(x) = \frac{2(b-x)}{(b-a)(b-c)} \quad \text{For } c \le x \le b \text{ ……………………………………………………..…..….(5.6b)}$$

where,
a and b = the lower and upper limits respectively
c = mode

PERT: Like the triangular distribution, this also has a lower limit, upper limit and a mode (most likely value). Values around the mode are more likely to occur. However values between the mode and extremes are more likely to occur than the triangular; that is, the extremes are not as emphasized. This is a special case of beta distribution, which is given by equation 5.7

$$P(x) = \frac{1}{B(\alpha_1,\alpha_2)} \frac{(x-a)^{\alpha_1 - 1}(b-x)^{\alpha_2 - 1}}{(b-a)^{\alpha_1+\alpha_2-1}} \quad \text{……………………………………………………..……………(5.7)}$$

$$\alpha_1 = \frac{4c+b-5a}{b-a} \qquad \alpha_2 = \frac{5b-a-4c}{b-a}$$

Discrete: It is a distribution that takes into account specific values that may occur and the likelihood of each. Unlike the continuous distribution, which can take any values between two specified values, discrete distributions are whole number distributions. Among the common discrete probability distributions are Binomial, Hypergeometric, Multinomial and Poisson distributions. With a discrete probability distribution, each possible value of the discrete random variable can be associated with a non-zero probability. Thus, a discrete probability distribution can always be presented in tabular form.

5.4.3 Advantages of Monte Carlo simulation

During a Monte Carlo simulation, values are sampled at random from the input probability distributions. Each set of samples is called iteration, and the resulting outcome from that sample is recorded. Monte Carlo simulation does this hundreds or thousands of times, and the result is a probability distribution of possible outcomes. In this way, Monte Carlo simulation provides a much more comprehensive view of what may happen. It presents not only what could happen, but also how likely it is to happen.

Monte Carlo simulation provides a number of advantages over deterministic, or "single-point estimate" analysis:

- **Probabilistic Results:** Results show not only what can happen, but also how likely each outcome is.
- **Graphical Results**: Because of the data a Monte Carlo simulation generates, it is easy to create graphs of different outcomes and their chances of occurrence. This is important for communicating findings to other stakeholders.
- **Sensitivity Analysis**: With just a few exemplars, deterministic analysis makes it difficult to see which variables impact the outcome the most. In Monte Carlo simulation, it is easy to see which inputs have the biggest effect on bottom-line results.
- **Scenario Analysis**: In deterministic models, it is very difficult to model different combinations of values for different inputs to see the effects of truly different scenarios. Using Monte Carlo simulation, analysts can see the exact combination of inputs when certain outcomes occur. This is invaluable for pursuing further analysis.
- **Correlation of Inputs**: In Monte Carlo simulation, it is possible to model interdependent relationships between input variables. This is important to represent how, in reality, when some factors goes up, others go up or down accordingly.

5.5 Results and Discussion

5.5.1 Monte Carlo Simulation results

Tables 5.3 and 5.4 presents the Monte Carlo simulation results for the Raw water turbidity – Power consumption, and Power consumption – water production volume models. The results for the other models are presented later in this chapter.

5.5.1.1 Raw water turbidity – Power consumption model

Input: Turbidity
Output: Power consumption (1000 kWh)
Number of Random numbers: 5000
Number of simulations: 5000

Table 5.3: Monte Carlo simulations results for Raw water turbidity-Power consumption model

Modeling Scenario	Mean of input (Degree)	Standard Deviation of input	Mean of output (1000kwh)	Standard Deviation of output	Standard Error	For 95% Confidence		For 99% Confidence	
						LCL	UCL	LCL	UCL
Training set	2.236	0.522	5449.29	111.016	1.570	5446.21	5452.37	5445.25	5453.33
BC_{TUR}	3.275	0.522	5625.52	74.489	1.053	5623.46	5627.58	5622.81	5628.23
TUR_5	3.439	0.522	5650.69	70.813	0.969	5670.26	5674.06	5669.66	5674.66
TUR_{10}	3.602	0.522	5672.16	68.536	0.924	5690.63	5694.25	5690.06	5694.82
TUR_{15}	3.766	0.522	5692.44	65.306	0.901	5712.24	5715.78	5711.69	5716.33
TUR_{20}	3.930	0.522	5714.01	63.715	0.858	5730.50	5733.86	5729.97	5734.39
TUR_{25}	4.094	0.522	5732.18	60.702	0.731	5818.23	5821.09	5817.78	5821.54
TUR_{50}	4.912	0.522	5819.66	51.711	0.555	5957.95	5960.13	5957.61	5960.47
TUR_{100}	6.550	0.522	5959.04	39.278	0.447	6067.00	6068.76	6066.73	6069.03
TUR_{150}	8.818	0.522	6067.88	31.590	1.570	5446.21	5452.37	5445.25	5453.33
TUR_{MAX}	100	0.522	7441.88	3.157	0.045	7441.79	7441.97	7441.77	7441.99

LCL: Lower Confidence Limit; UCL: Upper Confidence Limit

5.5.1.2 Power consumption – Water production volume model

Input: Power consumption (1000 kWh)
Output: Water supply volume (10^6 m^3)
Number of Random numbers: 5000
Number of simulations: 5000

Table 5.4: Monte Carlo simulations results for Power consumption – Water production volume model

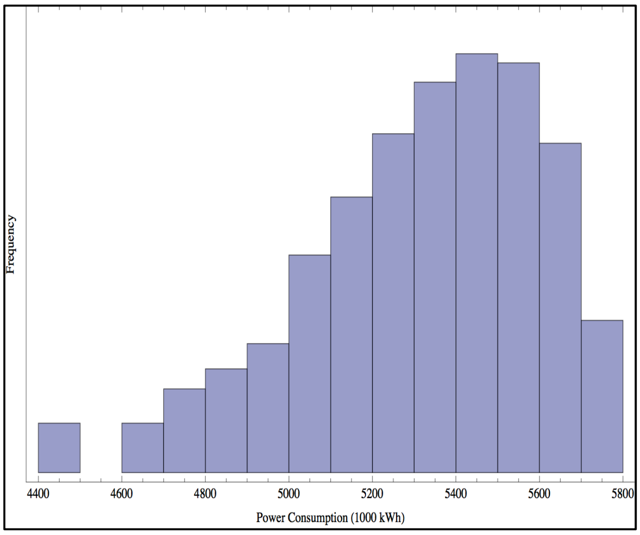
Modeling Scenario	Mean of input (1000 kWh)	Standard Deviation of input	Mean of output (10^6 m^3)	Standard Deviation of output	Standard Error	For 95% Confidence		For 99% Confidence	
						LCL	UCL	LCL	UCL
Training set	5521.010	251.858	16.591	0.682	9.6×10^{-3}	16.57	16.61	16.57	16.62
BC_{GHG}	5552.209	251.858	16.686	0.678	9.6×10^{-3}	16.67	16.71	16.66	16.71
GHG_5	5274.599	251.858	15.921	0.687	9.7×10^{-3}	15.90	15.94	15.90	15.95
GHG_{10}	4996.988	251.858	15.198	0.681	9.6×10^{-3}	15.18	15.22	15.17	15.22
GHG_{15}	4719.378	251.858	14.446	0.676	9.6×10^{-3}	14.43	14.46	14.42	14.47
GHG_{20}	4441.767	251.858	13.686	0.687	9.7×10^{-3}	13.67	13.71	13.66	13.71
GHG_{25}	4164.157	251.858	12.946	0.692	9.8×10^{-3}	12.93	12.97	12.92	12.97

LCL: Lower Confidence Limit; UCL: Upper Confidence Limit

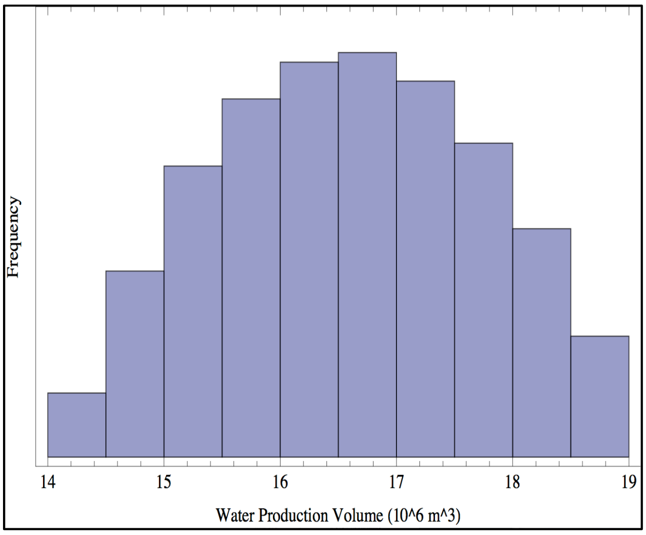
The outputs in Tables 5.3 and 5.4 are the average monthly values of Power consumption and Water production volume respectively. To convert to annual data, the output values in the respective tables must be multiplied by 12.

Tables 5.3 and 5.4 each have ten columns. The first column describes the modeling scenario used. For each model, the first scenario used is Monte Carlo simulation with the input data of the training set. The objective of doing this was twofold — First, to obtain the magnitude of the standard deviation, which would be then used as the common standard deviation for the input data of all the subsequent scenarios, as seen in the third column of the tables. Second, to have a preliminary idea of the output distribution function. The second column is the mean of the input set, respectively. For the different scenarios, the mean values correspond to the values previously tabulated in Tables 5.1 and 5.2. Columns 4 and 5 are the mean and standard deviation of the output, after 5000 Monte Carlo simulations. The sixth column is the standard error for each condition, based on which the upper and lower confidence limits for 95 and 99% have been calculated in Columns 7,8,9 and 10. It can be seen that for all models, the mean output can be stated with 99% confidence level because of the low standard error.

Figure 5.4 shows the frequency distributions of the outputs for the training set of each model. It can be seen that the distributions for all cases are more or less normal. Hence, the mean value of the output has been taken as the most probable value of the output.



(a)



(b)

Figure 5.4: Frequency distribution for output training sets for (a) Power consumption (b) Water production volume

5.5.2 Modeled power consumption under scenarios of climate change

Figure 5.5 shows the modeled power consumption for Kobe City Waterworks under different scenarios of climate change – reduction in GHG emissions, and increase in raw water turbidity.

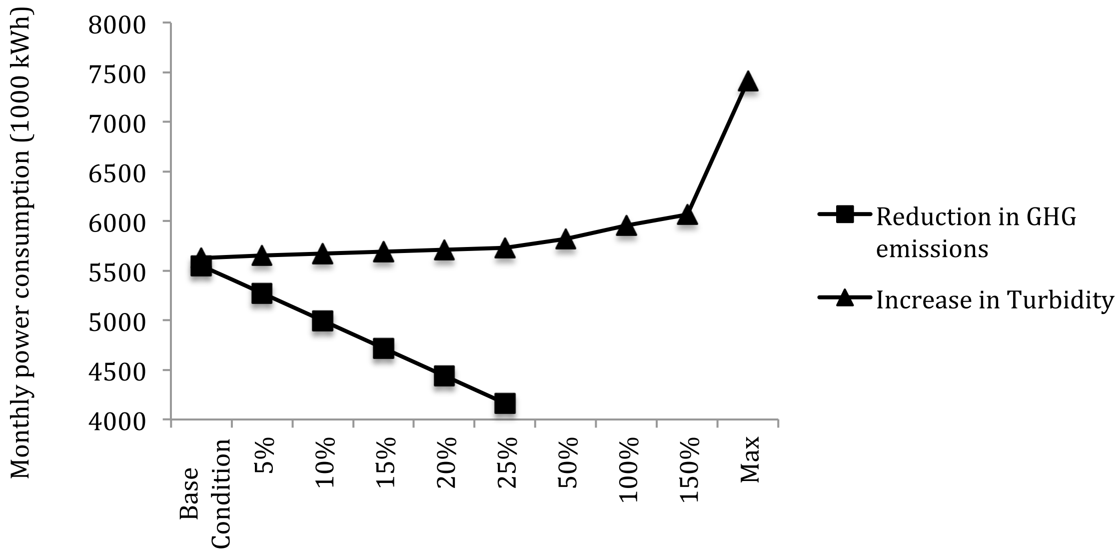


Figure 5.5: Trend of expected power consumption under scenarios of climate change

Accordingly, it can been seen that in order to reduce the GHG emissions the power consumption must decrease, if no additional sources of energy are available. For example, to achieve a 25% reduction of GHG emissions from the base condition, the power consumption will need to be reduced to around 4.2 x 10^6 kWh. However, with increase in raw water turbidity due to climate change, the power consumption is likely to increase. This is to ensure that the water quality will not suffer, and consumers are provided with the same quality that is currently available. Hence, in order to meet the emission targets the utility will not only have to reduce the power consumption required to reduce GHG emissions, but also take into account the power consumption required to counter the effects of increase in raw water turbidity.

Figure 5.6 shows the required reduction in monthly power consumption required under different scenarios. Accordingly, it is observed that with increase in raw water turbidity, more reduction in power consumption is required. Understandably, the rate of reduction increases, as the emission targets get more intense – the rate of reduction for 25% reduction in GHG emission is almost three times the rate for 5% reduction in GHG emissions. Table 5.5 presents the actual values of monthly reduction in power consumption required for all scenarios. The Kobe City Waterworks can use this table as a reference to decide which of the emission targets they would like to pursue. It must be mentioned that this table has been developed without considering the option of using renewable energy like solar or wind. In case options of renewable energy are available, the magnitude of required reduction in power consumption in Table 5.5 will decrease.

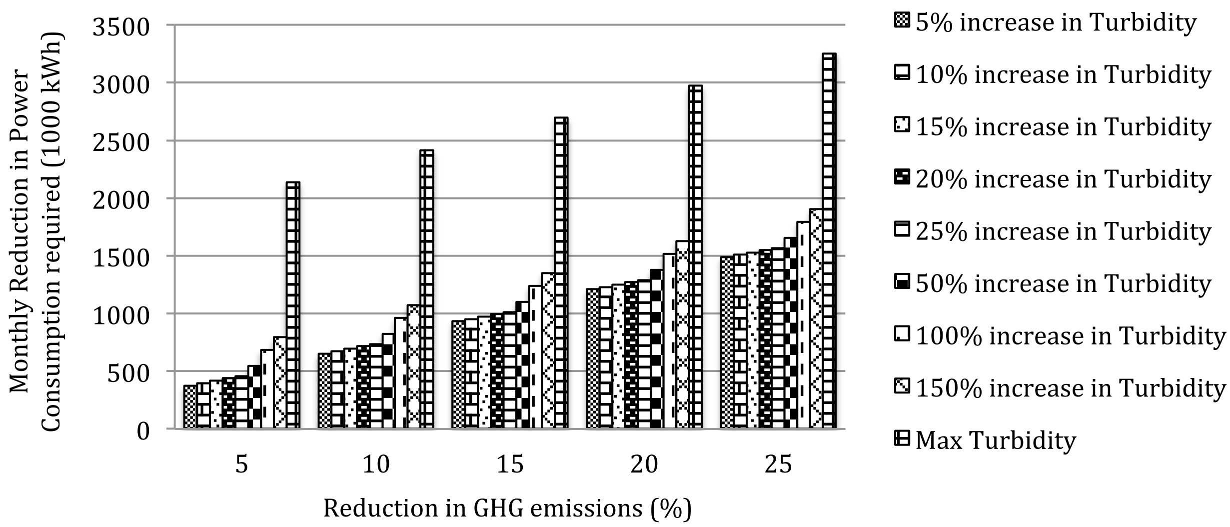


Figure 5.6: Target reduction in power consumption for Kobe City Waterworks for various scenarios of reduction in GHG emissions and increase in raw water turbidity

Table 5.5: Required reduction in power consumption (1000 kWh) for Kobe City Waterworks under different scenarios of climate change

	Reduction in GHG emissions from base condition (%)				
Raw water turbidity (Degrees)	**5**	**10**	**15**	**20**	**25**
3.439	376.09	653.70	931.31	1208.92	1486.53
3.602	397.56	675.17	952.78	1230.39	1508.00
3.766	417.84	695.45	973.06	1250.67	1528.28
3.930	439.41	717.02	994.63	1272.24	1549.85
4.094	457.58	735.19	1012.80	1290.41	1568.02
4.912	545.06	822.67	1100.28	1377.89	1655.50
6.550	684.44	962.05	1239.66	1517.27	1794.88
8.818	793.28	1070.89	1348.50	1626.11	1903.72
100	2139.40	2417.01	2694.62	2972.23	3249.84

Table 5.5 also provides the Kobe City Waterworks a reference to plan their future operations and treatment technology. For example, if the utility realizes that the reduction of power consumption to achieve 25% GHG reduction and turbidity 8 Degrees (1.9×10^6 kWh) is too much, they can consider

investing in newer equipment and changing the treatment technology which can reduce power consumption, while maintain the quality of water.

5.5.3 Effect of climate change on selected component of the 9-cPIS

Three models were developed to explore the relationship between the water production volume and three components of the 9-cPIS – Financial Sustainability, Economic Value of Water and Green Water Supply. The aim of developing these models was to examine the effect of climate change (reduction in GHG emissions) on the selected components of the 9-cPIS, so that tradeoff analysis could be performed. Tables 5.6 through 5.8 present the Monte Carlo simulation results of the three models under scenarios of reduction in GHG emissions.

All values of the selected components of the 9-cPIS are actual values, and not standardized.

For Tables 5.6 through 5.8, the input data is the water production volume, which is the output of the Power consumption – Water production volume model, previously presented in Table 5.4. However, it must be noted that while the output of water production volume in Table 5.4 is the average monthly volume, the inputs in Table 5.6 and 5.7 are the annual volume of production (average monthly volume x 12). The input values in Table 5.8, however, are monthly values.

Accordingly from Table 5.6, it is seen that with reduction in GHG emissions, the Financial Sustainability increases. The reason is because in the Kobe City Waterworks, the cost of producing water is more than its selling price. Thus, the 'revenue to cost ratio of water', which is an important contributing variable of the Financial Sustainability indicator, is less than one. As seen in previous models, reduction in GHG emissions is associated with reduction in production volume, and this will cause the net loss (selling price minus cost price of water) to reduce, thereby improving the Financial Sustainability. This augurs well for the Kobe City Waterworks because it means that attempts to achieve the GHG emission targets will not cause any financial harm to the utilities.

From Table 5.7, however it is seen that the Economic Value of Water decreases with reduction in GHG emissions, resulting from reduced water production. This is understandable because the main variables contributing to the Economic Value of Water are the 'water supply revenue' and the 'unit price of water'. With reduced water production, the water supply revenue will naturally reduce. Also in Kobe City Waterworks, the price of water does not change often – once in 7 or 8 years. Hence, with dwindling water supply revenue and constant price of water, the Economic value of water will reduce.

5.5.3.1 Water production volume – Financial Sustainability model

Input: Water production volume (10^6 m^3)
Output: Financial Sustainability
Number of Random numbers: 5000
Number of simulations: 5000

Table 5.6: Monte Carlo simulations results for Water production volume – Financial sustainability model

Modeling Scenario	Mean of input (10^6 m^3)	Standard Deviation of input	Mean of output	Standard Deviation of output	Standard Error	For 95% Confidence		For 99% Confidence	
						LCL	UCL	LCL	UCL
Training set	203.611	5.016	0.987	0.027	1.36×10^{-4}	0.9867	0.9873	0.9867	0.9873
BC_{GHG}	200.236	5.016	1.004	0.027	1.36×10^{-4}	1.0037	1.0043	1.0037	1.0043
GHG_5	191.046	5.016	1.054	0.027	1.37×10^{-4}	1.0537	1.0543	1.0536	1.0544
GHG_{10}	182.374	5.016	1.100	0.026	1.36×10^{-4}	1.0997	1.1003	1.0997	1.1003
GHG_{15}	173.346	5.016	1.148	0.026	1.36×10^{-4}	1.1477	1.1483	1.1477	1.1483
GHG_{20}	164.232	5.016	1.197	0.027	1.37×10^{-4}	1.1967	1.1973	1.1966	1.1974
GHG_{25}	155.351	5.016	1.244	0.027	1.39×10^{-4}	1.2437	1.2443	1.2436	1.2444

LCL: Lower Confidence Limit; UCL: Upper Confidence Limit

5.5.3.2 Water production volume – Economic Value of Water model

Input: Water production volume (10^6 m^3)
Output: Economic Value of Water
Number of Random numbers: 5000
Number of simulations: 5000

Table 5.7: Monte Carlo simulations results for Water production volume – Economic Value of Water model

Modeling Scenario	Mean of input (10^6 m^3)	Standard Deviation of input	Mean of output	Standard Deviation of output	Standard Error	For 95% Confidence		For 99% Confidence	
						LCL	UCL	LCL	UCL
Training set	200.851	3.092	99.900	1.280	1.82×10^{-2}	99.864	99.936	99.853	99.947
BC_{GHG}	200.236	3.092	99.642	1.284	1.80×10^{-2}	99.578	99.648	99.567	99.659
GHG_5	191.046	3.092	95.826	1.276	1.77×10^{-2}	95.805	95.875	95.794	95.886
GHG_{10}	182.374	3.092	92.314	1.254	1.75×10^{-2}	92.267	92.335	92.256	92.346
GHG_{15}	173.346	3.092	88.538	1.240	1.78×10^{-2}	88.518	88.588	88.507	88.599
GHG_{20}	164.232	3.092	84.813	1.262	1.82×10^{-2}	84.810	84.882	84.799	84.893
GHG_{25}	155.351	3.092	81.127	1.287	1.83×10^{-2}	81.116	81.188	81.105	81.199

LCL: Lower Confidence Limit; UCL: Upper Confidence Limit

5.5.3.3 Water production volume – Green Water Supply model

Input: Water production volume (10^6 m^3)
Output: Green Water Supply
Number of Random numbers: 5000
Number of simulations: 5000

Table 5.8: Monte Carlo simulations results for Water production volume – Green Water Supply model

Modeling Scenario	Mean of input (10^6 m^3)	Standard Deviation of input	Mean of output	Standard Deviation of output	Standard Error	For 95% Confidence		For 99% Confidence	
						LCL	UCL	LCL	UCL
Training set	16.556	0.700	2.462	0.087	1.2×10^{-3}	2.460	2.464	2.459	2.465
BC_{GHG}	16.686	0.700	2.447	0.088	1.2×10^{-3}	2.445	2.449	2.444	2.450
GHG_5	15.920	0.700	2.538	0.088	1.2×10^{-3}	2.536	2.540	2.535	2.541
GHG_{10}	15.198	0.700	2.631	0.088	1.2×10^{-3}	2.629	2.633	2.628	2.634
GHG_{15}	14.446	0.700	2.727	0.089	1.3×10^{-3}	2.725	2.729	2.724	2.730
GHG_{20}	13.686	0.700	2.824	0.089	1.3×10^{-3}	2.822	2.826	2.821	2.827
GHG_{25}	12.946	0.700	2.914	0.088	1.2×10^{-3}	2.912	2.916	2.911	2.917

LCL: Lower Confidence Limit; UCL: Upper Confidence Limit

However, this is not such a serious concern as it sounds. The main objective of introducing the Economic Value of Water as one of the components of the 9-cPIS was to ensure that the true value of water, and its production is not lost on the consumers. Hence, even though the Economic Value may drop due to reduced supply, as long as the water is priced appropriately, reflecting the true production cost, there should be no concern.

From Table 5.8, it is seen that the Green Water Supply increases with reduction in GHG emissions. This again is quite natural since the GHG emissions are directly proportional to the volume of water produced. For the Kobe City Waterworks, electricity is the only form of energy used for water production and pumping, and is responsible for all GHG emissions. Hence, with reduced water production, there will be less GHG emissions, resulting from power consumption, thereby improving the Green Water Supply.

Figure 5.7 shows the output distribution of Financial Sustainability, Economic Value of Water and Green Water Supply respectively, with the input data of the training sets. It is seen that all three distributions are normal in nature and thus the mean value of the output can be considered as the most probable output value.

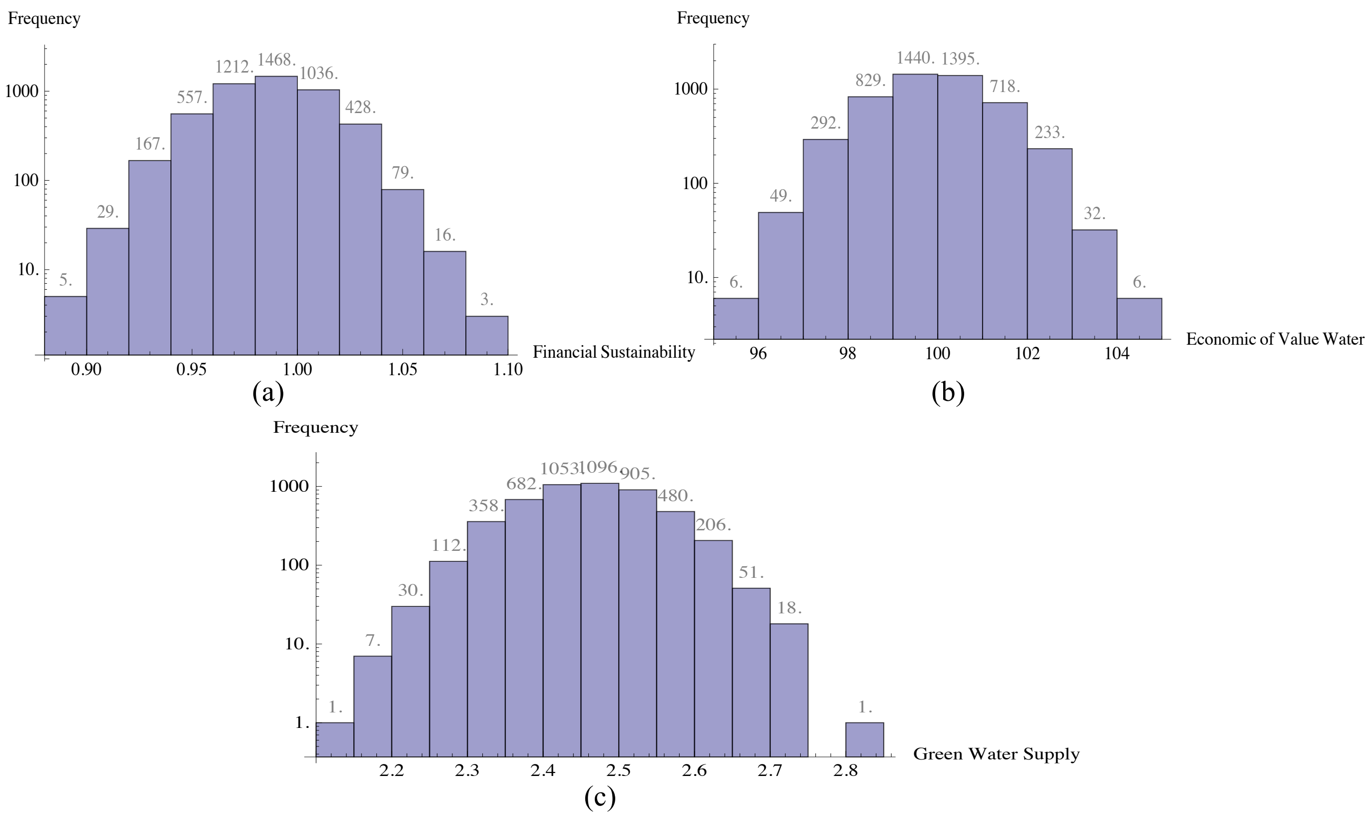


Figure 5.7: Frequency distribution for output training sets for (a) Financial Sustainability (b) Economic Value of Water (c) Green Water Supply

Figure 5.8 shows the trend of the three selected components of the 9-cPIS from 2006 to 2010, and then under different scenarios of GHG emission reduction. From 2006 through 2010, a very slight decrease in Financial Sustainability is observed, because of small fluctuations in revenues and costs.

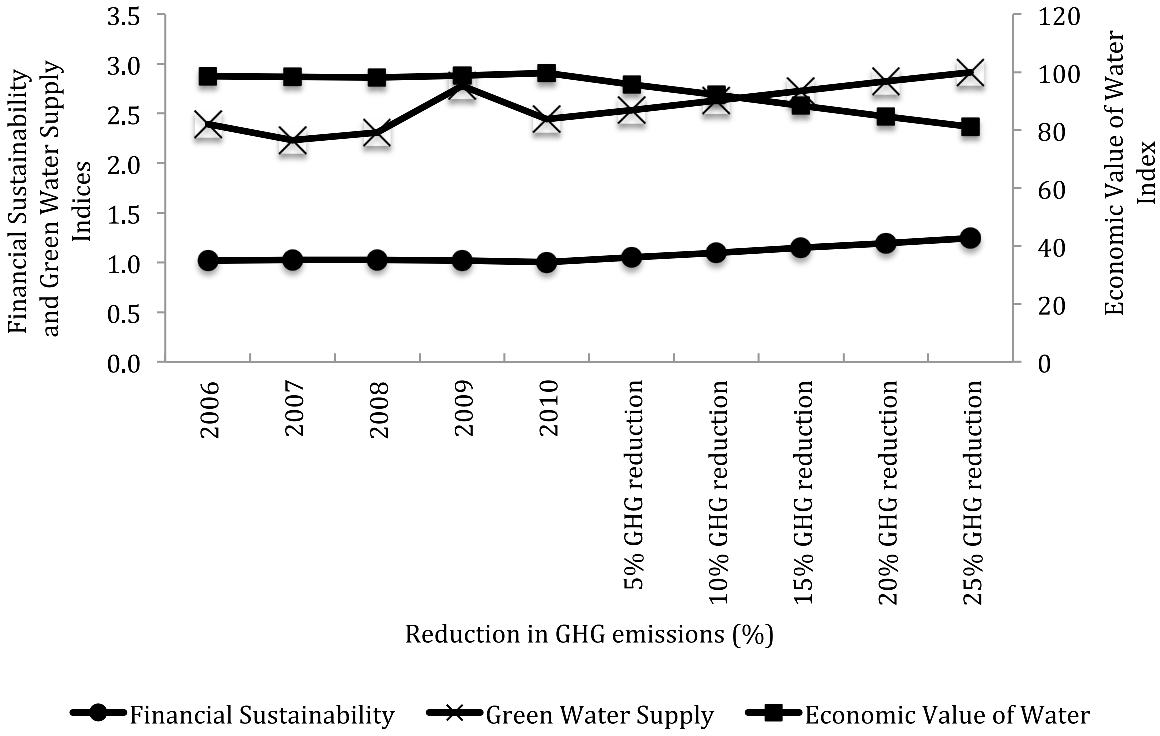


Figure 5.8: Trends of selected components of the 9-cPIS based on historical data and scenarios of GHG reduction

Based on actual data presented earlier in Figure 4.5 of Chapter 4, it was pointed out that the water production volume has decreased from 200.321 x 10^6 m^3 in 2006 to 196.5 x 10^6 m^3 in 2010. This should ideally warrant an increase in the Financial Sustainability. However, the reduction of 3.821 x 10^6 m^3 is too small to make any significant change in the Financial Sustainability. Hence, the Financial Sustainability does not show any major/sharp movement from 2006 to 2010 in Figure 5.8. To achieve 5% reduction in GHG emissions, the production volume suddenly drops 191.04 x 10^6 m^3 (calculated from Table 5.4 previously presented). Because of this, there is a noticeable upward movement of the Financial Sustainability in Figure 5.8, which continues for further reductions in GHG emissions. It is important to point out here that the magnitudes of Financial Sustainability for Kobe City Waterworks from 2006 onwards have been above 1 (one). This is particularly encouraging because the Financial Sustainability is basically a ratio of revenues to costs, and any value above 1 means that the revenues are greater than the costs.

The Green Water Supply has generally showed a decreasing trend from 2006 to 2010, with just a sudden rise in 2009. This can be attributed to the fact that in 2009, the water production volume was the least at 191.04 x 10^6 m^3 (previously presented in Figure 4.5). With reduction in GHG emissions, the water production volume will decrease, thereby justifying the upward movement of the Green Water Supply for the different scenarios of GHG emissions reduction.

The Economic Value of Water has generally shown a decreasing trend from 2006 to 2010 and is further expected to decrease under the different scenarios of GHG emissions reduction. As explained earlier, this is due to reduced revenues, resulting from reduced supply. As also pointed out before, this is not too much of a concern as long as the water price does not drop down to a level where the consumers begin to have a wasteful attitude towards water.

5.5.4 Public Interest under scenarios of change

In order to design the tradeoff between the consumer expectations of water quality and the reduction in energy use, the Public Interest (P_{INT}), introduced earlier in Chapter 3, has been used. It may be recalled that in the questionnaire survey carried out to quantify the P_{INT}, respondents were asked questions about how important certain areas of the supply system were to them. It can be reasoned that if a respondent indicates a particular area of the supply system as important, it means that he/she has some natural expectations from the utility with respect to that area. For example, if the respondent states that 'tap water quality' is important to him/her, it can be understood that he/she expects the tap water quality to conform to certain standards that he/she thinks are adequate.

The regression equation for P_{INT}, developed previously in section 3.5.3.4 of Chapter 3, has five independent variables — Trust in water utility, Good quality tap water, Equity of distribution, R&D in utility and water price. The magnitude of the P_{INT} will be greater if the coefficients of the five independent variables have larger values, and if the coefficients have large values it follows that the consumer expectations are being met better. Hence P_{INT} is synonymous with 'meeting consumer expectations.

To calculate the P_{INT} (or 'meeting consumer expectations) under different scenarios of climate change (reduction in GHG emissions), the values of the Financial Sustainability, Economic Value and Green Water Supply indices from Tables 5.6, 5.7 and 5.8 respectively were used in the MLR equation 3.11, developed earlier in section 3.5.4.3. The said MLR equation was developed to relate the P_{INT} with all the components of the 9-cPIS together. Figure 5.9 shows the trend of the P_{INT}, under different scenarios of reduction of GHG emissions. It is seen that the P_{INT} decreases uniformly with increased reduction in GHG emissions.

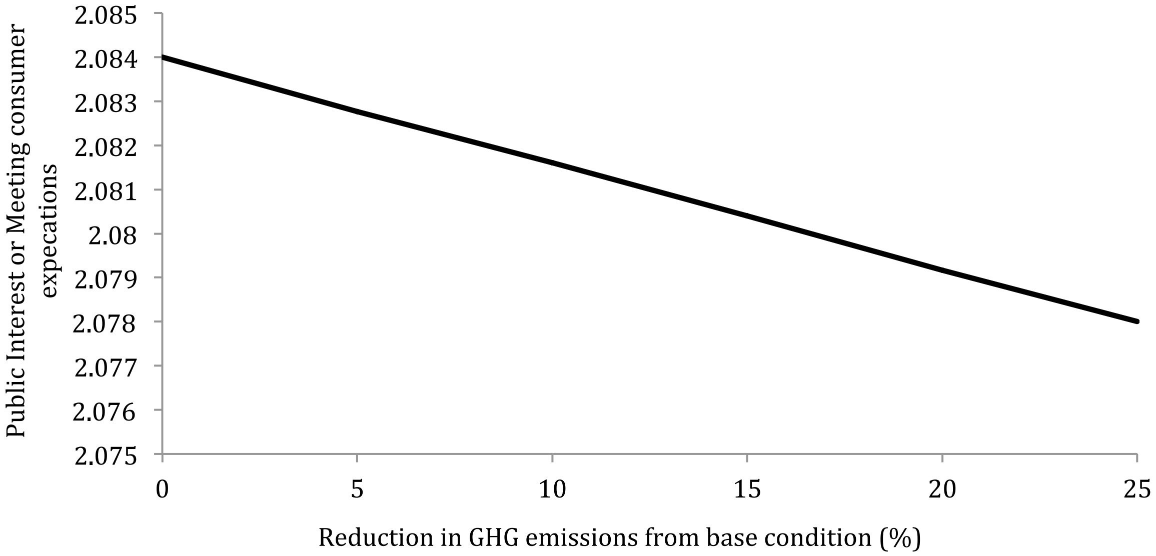


Figure 5.9: Trend of P_{INT} for various scenarios of reduction in energy use

This suggests that in an effort to reduce the GHG emissions, meeting consumer expectations becomes more challenging. This is understandable because reduction in GHG emissions can be achieved in three ways:

- Reduced water production volume
- Increased use of renewable energy
- Improved efficiency of equipment

All these measures can cause a loss of revenue and reduced financial security. This can very well lead to increased water prices and low water quality because of heavy investment in installation of renewable energy, thereby causing a reduction in meeting consumer expectations.

To understand the implications of the reducing trend of the P_{INT} with reductions in GHG emissions, it is important to analyze the trends of each variable of the P_{INT} under scenarios of change.

The first variable is 'Good quality tap water'. With reduction in GHG emissions, the power consumption will reduce unless there is an immediate provision for renewable energy. Under reduced power consumption, it will be difficult to pursue more advanced treatment systems because such systems are usually energy intensive. Table 5.9 shows the average energy requirement for different advanced treatment systems in the USA and Canada, taken from a report published by the American Water Works Association (AWWA, 2008).

Table 5.9: Energy requirement for various advanced water treatment technologies

Treatment System	Process or Component	Specific Energy Consumption (kWh/1000 gal)
UV disinfection	Medium-pressure lam system	0.02-0.09
Ozone disinfection	LOX feed	0.02-0.05
	VPSA feed	0.06-0.08
	Ambient air feed	0.11-0.16
Micro-filtration/Ultra-filtration	Pumps, air scouring, cleaning system	0.4-1.0
Reverse osmosis	Feed pumps	0.5-4.8

* All values are based on selected case studies in USA and Canada
Source: AWWA Research Foundation

Accordingly it is evident that for more advanced levels of water treatment, the energy consumption is more. Hence, it can be established that ***in an effort to reduce GHG emissions, the quality of tap water may not improve, suggesting that this variable can partly explain the reduction of the P_{INT} under scenarios of reduction in GHG emissions.***

The second variable is 'Trust in water supplier'. This is intrinsically related with good tap water quality, meaning that if the quality of tap water is not satisfactory, the consumers are not likely to trust the suppliers. It might be argued that the trust in water suppliers may also be influenced by reliability of service, like in most developing countries. However, reliability of services is not really a concern in Japan, where more than 97% of the population has access to continuous water supply. Thus, ***with reduction in GHG emissions, the consumer's trust in water utilities is likely to diminish because of inadequate water quality***.

The third variable is the 'Research and Development' in utilities. Any efforts that the utility takes towards reducing the GHG emissions will require some form of technological input. These may include the use of renewable energy, or improving the efficiency of pumps etc., both of which require the latest technology. Hence, there is every possibility that the 'Research and Development' in utilities is likely to improve with efforts to reduce the GHG emissions, thereby suggesting that this variable will cause a rise in P_{INT}. Hence, it can be inferred that ***'Research and Development' is not responsible for the decrease in P_{INT}*** as seen in Figure 5.9.

The fourth variable is the 'Equity of distribution'. The equity of distribution deals with supplying an adequate quantity of water to all consumers under any situation. In order to reduce GHG emissions it is possible that utilities may consider lowering the water production. However, even if the water production volume is reduced the quantity of water supplied will, in all likelihood, meet the consumer demands because the per capita consumption is declining anyways. More importantly, given the current policy of distribution, it is unlikely that there will be bias in supply when the production volume is reduced. Further, in Japan drinking water supply sector has priority over the other sectors, meaning that even in conflicting situations the consumers' demands will be met without bias. Hence, ***'Equity of distribution' is not likely to be affected by reductions in GHG emissions***, suggesting that the decrease in P_{INT} is unlikely to be influenced by this variable.

The last variable is the 'Water price'. In a bid to reduce the GHG emissions, if utilities decide to only lower the water production then it may not cause a significant effect on the water price. However, if the utilities decide to invest in renewable energy then the cost of installation and operation will have to be reflected in water fees, thereby causing a hike in water fees. Additionally, if the utility decides to improve on the treatment technology, the costs will increase leading to rise in water prices, if subsidies from the government are not available. Hence, ***the decrease in P_{INT} for different scenarios of GHG reduction can also be partly explained by a possible increase in water price***. However, the water price is the least significant variable of the P_{INT} factor (seen previously in equation 3.1), so it can be speculated that the water price will make only a marginal contribution to the decrease in P_{INT}.

From the discussion above, it is clear that 'Research and Development' and 'Equity of distribution' will either increase or remain constant under the various scenarios. Thus, these variables cannot be associated with the reduction in P_{INT} observed in Figure 5.9. Among the other variables, although the 'Water price' causes the P_{INT} to decrease, the affect is small because 'Water price' is the least significant variable of the P_{INT} factor. Hence, only two variables are responsible for the reduction in P_{INT}, under different scenarios of GHG emissions reduction – 'Good quality tap water' and 'Trust in suppliers'. Also, as pointed out earlier in this section 'Trust in suppliers' depends heavily on the quality of drinking water, it can be thus inferred that 'Good quality tap water' is the single most important variable that can explain the reduction in P_{INT}.

Thus, this study suggests that the decrease in P_{INT}, under scenarios of GHG emissions reductions, is most likely to be caused by inadequate water quality. In other words, the consumer expectations of water quality is not likely to be met with reductions in GHG emissions.

Hence, the y-axis in Figure 5.9 can be changed to 'meeting consumer expectations for water quality'. This revision is shown in Figure 5.10.

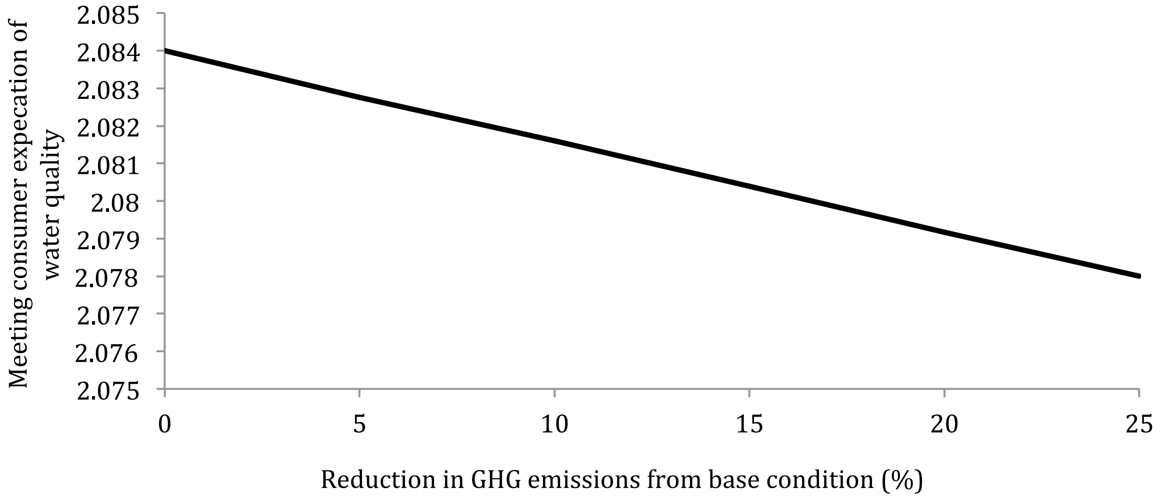


Figure 5.10: Trend of meeting consumer expectations of water quality for various scenarios of reduction in GHG emissions

5.5.5 Tradeoff between consumer expectations of water quality and energy use

The aim of the tradeoff analysis, in this context, is to arrive at an optimal value of GHG reduction such that there is a balance between reducing energy use and meeting consumer expectations of water quality. For example, by targeting a high GHG reduction, of say 25%, the utility will no doubt be able to reduce the energy use but in doing so it will be difficult for them to perform well on meeting consumer expectations. Conversely, by targeting a high value of meeting consumer expectations of water quality the targets of reducing energy use will suffer. Hence, the analysis aimed to arrive at such a value of GHG reduction where both targets would be achieved equally.

It is also important to note that the tradeoff analysis in this study is based on the assumption that both reducing energy use and meeting consumer expectations of water quality have equal weightage. Thus, both the entities of the tradeoff are considered equally important and should be measured in the same units. There may be a line of thought that considers one member of the tradeoff as more important than the other, which makes a case for different weightage for each member of the tradeoff. However, to do so would require converting the values of the members of the tradeoff into monetary or some common unit, based on additional analysis, which is beyond the scope of this study. This study has designed a tradeoff between two equals. Hence, the optimization problem has been simplified in this case is to identify that particular value of GHG reduction at which both reducing energy use and meeting consumer expectations of water quality have equal values. The concept of providing equal weightage to both the members of the tradeoff, in this case, is quite rational because in Japan both reducing energy use and meeting consumer expectations of water quality are equally prominent issues. While one issue is directly concerned with the well-being of consumers, the other is directly concerned with the well-being of the planet, which will ultimately have a cascading effect on consumers. Hence to prioritize one issue over the other may not so easy.

The target reduction in power consumption required for various cases of GHG reduction, under different scenarios of raw water turbidity, for Kobe City Waterworks has already been calculated in section 5.5.2. This has been shown graphically in Figure 5.11, for selected cases of raw water turbidity. Understandably, the required reduction in power consumption increases for more stringent cases of GHG emissions reductions or more severe cases of increase in raw water turbidity.

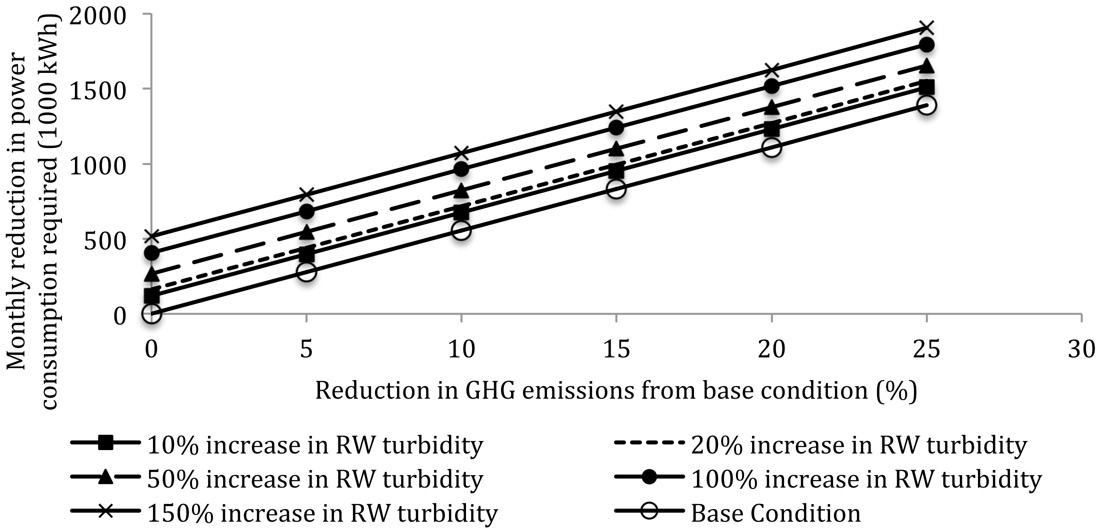


Figure 5.11: Reduction in power consumption required for Kobe City Waterworks for various scenarios of climate change

To facilitate the tradeoff between the consumer expectations of water quality and the reduction in energy use, Figures 5.10 and 5.11 will have to be combined so that both these variables are represented on the same graph, at the same time. This combination is shown in Figure 5.12. However, because the two variables have different units, some form of standardization technique is required to ensure reliability of results. The standardization formula used here is the same as that which has been used previously in this study, which can be revisited in section 2.8.1 (Equation 2.10). Standardization in this context is very important to warrant that the scale of the vertical axes does not affect analysis. For example, if the maximum value of the ordinate is y_1 units, in the absence of a standardization medium it is not possible to specify the maximum value for the scale of the y-axis because that choice is entirely up to the analyst. Hence, different analysts will obtain different values of the optimal tradeoff depending upon the scale of the axes used. Standardization of values overcomes this problem by ensuring that the scales of the vertical axes are fixed, thereby providing consistency in analyses across multiple users. Additionally, because both the members of the tradeoff have been given equal weightage, the same standardization scale has been used for both the primary and secondary axes. The choice of the standardization scale depends entirely up to the user (e.g. the user can standardize the values in the range -1 to 1 or 1 to 5 etc.) without impacting the interpretation of the results.

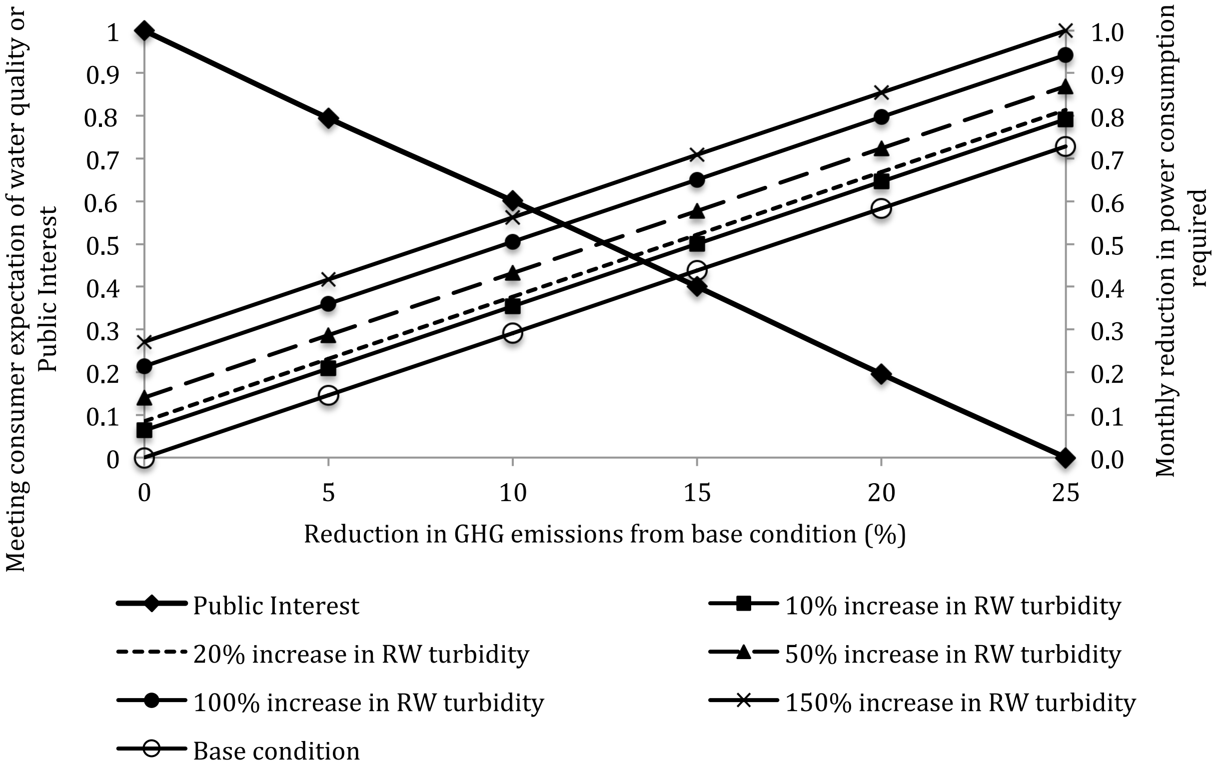


Figure 5.12: Standardized values of P_{INT} and reduction in power consumption required for Kobe City Waterworks for various scenarios of reduction in GHG emissions and increase in raw water turbidity

The methodology to obtain the optimal tradeoff between meeting consumer expectations of water quality and reduction in energy use is as follows

- Identify the expected increase in raw water turbidity based on climate change models or expert opinion
- Locate the point of intersection of the line corresponding to the expected increase in raw water turbidity with the P_{INT} line
- From the point of intersection, drop a vertical line downwards on the x-axis. It is only at this point of intersection that the standardized values of both meeting consumer expectations of water quality and reduction in energy use have equal values suggesting that this is the point where the two members of the tradeoff are balanced.

- The value of the x-axis is the reduction in GHG emissions that should be targeted to ensure optimal tradeoff between the consumer expectations of raw water quality and the reduction in energy use.
- For example, if the expected increase in raw water turbidity is 100% from the base condition, the coordinates of the intersection point are (0.55, 11.3). Hence, a maximum of 11.3% reduction in GHG emissions can be done to ensure optimal tradeoff between consumer expectations of water quality and reduction in energy use.

Figure 5.12 can be used by Kobe City Waterworks to identify the optimal tradeoff between meeting consumer expectations of water quality and reduction in energy use, for various conditions of expected increase in raw water turbidity. It is apparent that for more severe cases of increase in raw water turbidity, the optimal reduction in GHG emissions is less. This is to ensure that the water quality does not deteriorate significantly. For example, under the current situation of turbidity, the optimal reduction in GHG emissions is around 14.4% from base condition but for 150% increase in turbidity from base condition, the optimal reduction in GHG emissions from base condition is 10.5%.

5.5.6 Tradeoff between consumer expectations of water quality and energy use for various treatment systems

In the previous section a methodology was developed to estimate the optimal tradeoff between meeting the consumer expectations of water quality and reduction in energy use, for Kobe City Waterworks. The said water utility uses Rapid Sand Filtration (RSF) and Granulated Activated Carbon (GAC) to treat water before it is supplied to the consumers. This section attempts to examine the tradeoff relationship for other advanced forms of treatment. Like in the previous section, the basic assumptions of the tradeoff analysis in this section also remain the same, which is based on providing an equal weightage to both members of the tradeoff.

It can be discussed that there is a possibility that the trend of the consumer expectations of water quality will change because of the better water quality, which can very well shift the P_{INT} (or meeting consumer expectations of water quality) line upwards. However, it is very likely that the trend of reduction in energy use will also change, with an upward shift, because these advanced water systems use more energy. Because both the lines shift upwards simultaneously, there is a strong possibility that the net effect will ensure that the optimal GHG reduction remains unchanged. However, because of time constraints this aspect could not be verified in this study.

Two advanced treatment systems were studied – (a) GAC with Ozonation and (b) GAC + Ozonation + Ultra Violet treatment (UV). Both the treatment systems are used by another water utility (Osaka City

Waterworks Bureau), which is located close to the Kobe City Waterworks. The service population of both the utilities is more or less the same, suggesting that the scale of supply is comparable. Hence it can be, for modeling studies, assumed that if Kobe City Waterworks adopts either of these treatment systems, the operation features and statistics will be quite similar to those of Osaka Waterworks in its present state. The power consumption data for the treatment systems was obtained from the two utilities, and is described in Table 5.10

Table5.10: Unit power consumption for various treatment systems considered in the study

Treatment system	Power consumption (kWh/m^3)	Utility	Data Source
RSF + GAC	0.005	Kobe	Calculated from raw data
GAC + Ozonation	0.015	Osaka	Secondary data obtained from utility
GAC+ Ozonation + UV	0.07	Osaka	Secondary data obtained from utility

Expectedly, the data indicates that as the level of water treatment increases, the unit power consumption also increases. Hence, the more advanced treatment systems are more energy intensive.

Also observed in Table 5.10 is that

Power consumption for GAC + 0_3 = 3 * Power consumption for RSF +GAC……………………..….(5.8)

Power consumption for GAC + 0_3 + UV = 14 * Power consumption for RSF +GAC……….………..(5.9)

By multiplying the coefficients in equations 5.8 and 5.9 with the power consumption scenarios developed earlier for Kobe City Waterworks in section 5.5.2, tradeoffs were developed for the two treatment systems. A point of contention here is that although the unit power consumption data is for Osaka Waterworks Bureau, the water production volume data used is for Kobe City waterworks. However, as specified earlier in this section, the scale of supply for both Kobe and Osaka is almost the same – in terms of water production and the service population. Hence, the data was used interchangeably for this analysis.

The analysis for the two treatment systems (GAC + O_3 and GAC + O_3 + UV) was performed in the same manner as that for RSF + GAC, as seen previously in section 5.5.5. Figures 5.13 and 5.14 shows the tradeoff analysis for the two treatment systems respectively, while Figure 5.12 shown previously is the tradeoff analysis for the RSF + GAC treatment system

From Figures 5.12, 5.13 and 5.14 it can be seen that in all three treatment systems, the range of optimal GHG reductions lie between 10 and 15% from base condition. For most scenarios of increase in turbidity there is very little difference in the optimal reduction in GHG emissions. For example, for 100% increase in raw water turbidity from base condition, the optimal reductions of GHG emissions from base condition for RSF + GAC, GAC + O_3 and GAC + O_3 + UV treatments are 11.3%, 11.4% and 10.8% respectively.

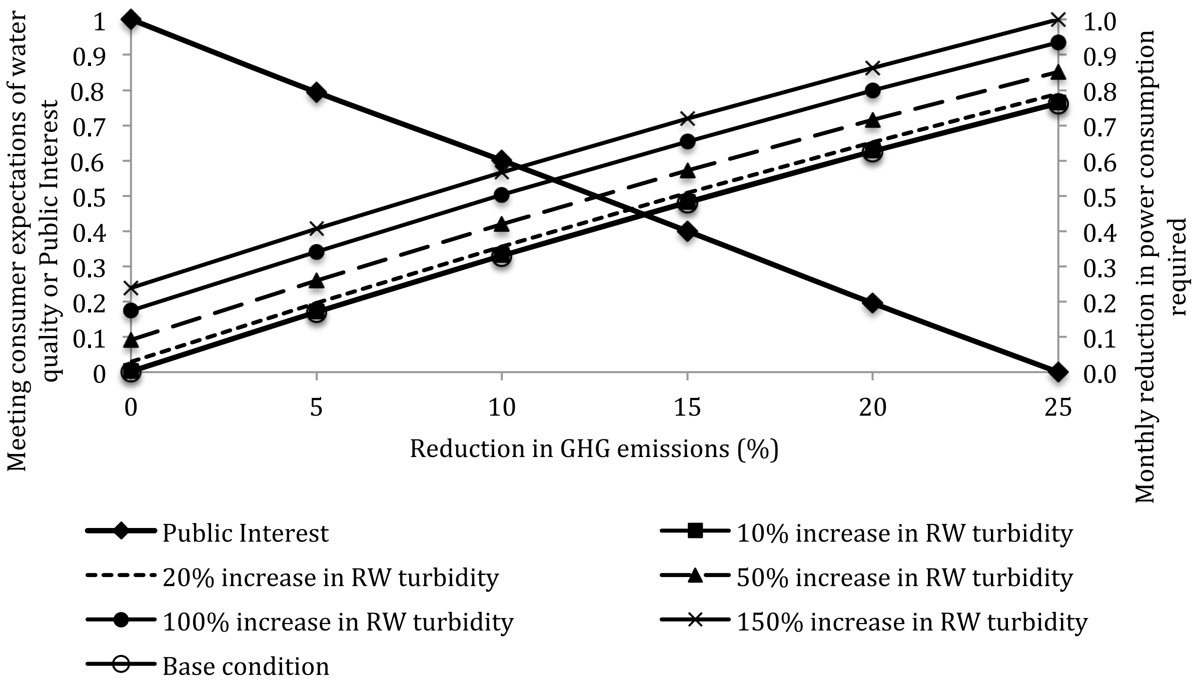


Figure 5.13: Tradeoff between P_{INT} and reduction in power consumption required for GAC + 0_3

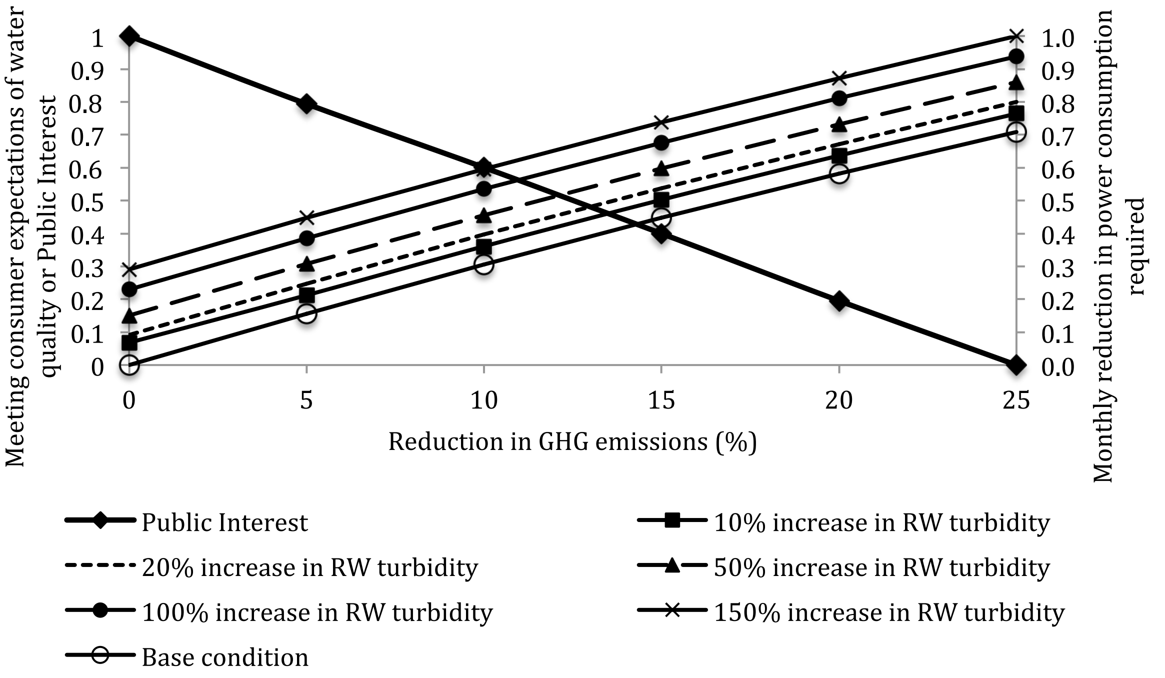


Figure 5.14: Tradeoff between P_{INT} and reduction in power consumption required for GAC + 0_3 + UV

It must be noted that Figures 5.12, 5.13 and 5.14 are not to be compared relatively because even though the optimal reduction for GAC + O_3 + UV is 10.8% in this case, the absolute value of reduction will be much higher when compared to the other two treatment systems. Figure 5.15 clarifies this explanation in a better way. It can be seen that the monthly reduction in power consumption for GAC + O_3 + UV treatment (14.83 Million kWh), to achieve 15% reduction in GHG emissions, is around 13.5 times the reduction required for RSF + GAC (1.10 Million kWh) for the same conditions. Similarly, the reduction in power consumption for GAC + O_3 treatment (2.82 Million kWh), to achieve 15% reduction in GHG emissions, is around 2.5 times the reduction required for RSF + GAC for the same conditions.

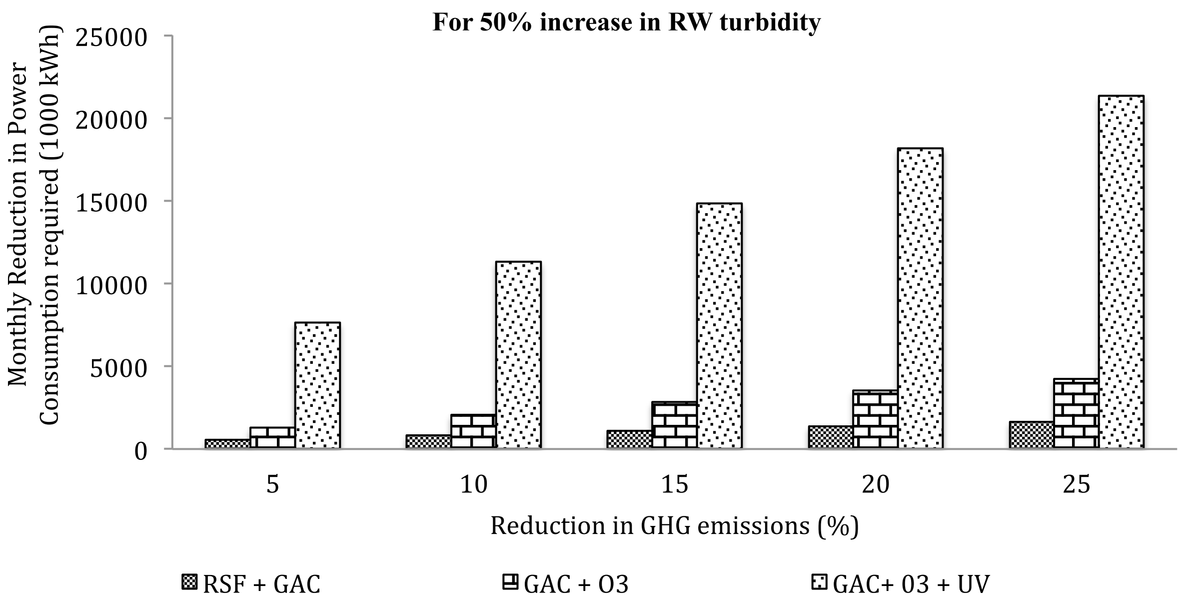


Figure 5.15: Reduction in power consumption required for the three treatment systems, for various scenarios of reduction in energy use

To understand the relative comparison between the three treatments systems, Figure 5.16 has been developed by considering the required reductions in power consumption for the three systems for 50% increase in raw water turbidity from base condition. It can be seen from Figure 5.16 that if the optimal GHG reduction for RSF + GAC treatment is around 18.7%, it is around 15.1% and 6.2% for GAC + O_3 and GAC + O_3 + UV treatments respectively. It is important to point out here that these values are only meant for relative comparison and are not to be taken as the absolute value for each treatment system. Thus it would be incorrect to say that if the utility uses GAC + O_3 + UV treatment, it should target an optimal tradeoff of 6.2%. This analysis must be performed separately using the methodology outlined in this section. Figure 5.16 only suggests that, for the same conditions, the optimal reduction in GHG emissions for RSF + GAC treatment is around 1.24 and 3 times the optimal reduction for GAC + O_3 and GAC + O_3 + UV treatments respectively.

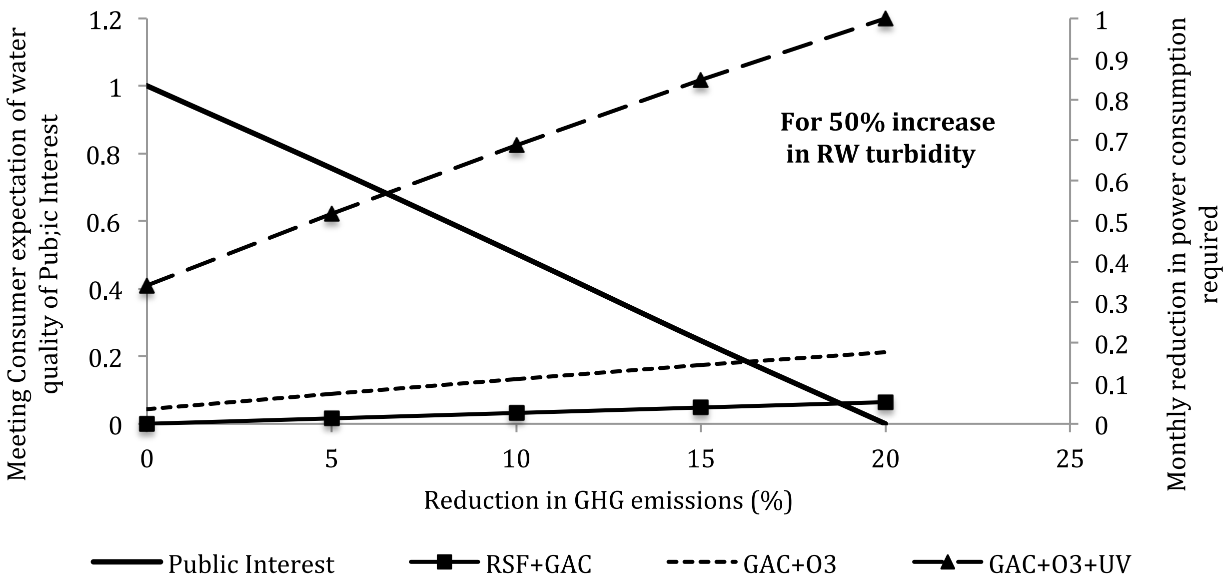


Figure 5.16: Relative comparison of optimal reduction in GHG emissions for three treatment systems

5.5.7 Scenarios based on per capita demand

In the previous sections (5.5.5 and 5.5.6), a methodology was developed to identify the optimal reduction in GHG emissions based on tradeoff between meeting consumer expectations of water quality and reducing energy use. From the tradeoff analysis results for Kobe City Waterworks, it was observed that the optimal reduction in GHG emissions ranges within 10.5% - 13.5% from base condition, for various scenarios of increase in raw water turbidity. To achieve reduction in GHG emissions, the utility will need to concentrate on three major thematic areas — reducing water production, improving efficiency of equipment, and increasing use of renewable energy. Ideally, the utility action plan should involve a combination of all the three measures for effective results.

This section of the study focuses on investigating the possible reduction in the water production to curtail GHG emissions. Reducing the water production is never an easy task for the utilities. First, it leads to a loss of revenue, thereby affecting the financial stability of the utility. Second, it may result in the consumers' demands not being met. While both the concerns are valid, it is the second concern which is perhaps more significant because it is imperative for the utility to meet the basic demand of its customers under all circumstances. From the background information about the Kobe City Waterworks, presented earlier in Chapter 4 (section 4.5.1), it was seen that the water production volume and the per capita demand have been declining over the last few years. Hence, it appears that there is a natural reduction in water production volume and per capita consumption. In light of the above, it may not be incorrect in assuming that the per capita consumption may very well decrease further in the years to come, and hence reducing water production will still result in all needs being met.

However, there is a limit up to which the per capita demand can reduce. There are certain basic water needs, which need to be fulfilled irrespective of the background/class/status of consumers, while some needs are site specific. In other words, there is a minimum per capita demand that the water utilities will have to meet, based on which there is a minimum water production volume. The amount of water production must always be equal to or greater than this minimum water production volume, even if it results in more GHG emissions.

The scenarios (or settings) is this section are based on estimating the minimum water supply volume that will need to be provided to meet the demands of the consumers. Water supply volume, in the context of this study, is the volume of water received by the consumer after accounting for all transmission and production losses. Hence,

$$\text{Water supply volume} = \text{Water production volume} - \text{Losses}$$

Based on the minimum water supply volume, the minimum power consumption can be estimated since there is a very strong relationship between the power consumption and the water supply/production volume as already seen in Chapter 4. This relationship will be presented again in the next section.

As observed earlier in Table 5.2, to reduce the GHG emissions, the power consumption will have to reduce. This endeavor will become even more challenging in light of increase in raw water turbidity. However, production, and thereafter water supply, requires power consumption, and in order to meet the minimal demand there is a limit up to which this power consumption can be reduced. The settings in this module address this important issue.

5.5.7.1 Water production volume – Power consumption model

To begin with, a relation will need to be established between the water production volume and power pconsumption. Using historical data of water production volume and power consumption, and the procedure outlined in Chapter 4, a regression model was developed between the water production volume and power production. Then based on water production values, water supply was calculated by deducting the relevant losses.

A total of 60 data exemplars were available to define the water supply volume – power consumption relationship, out of which 40 data points were used for developing the models (training) and 20 data points were used for testing the models (testing). Four sets of equations corresponding to Linear, Quadratic, Cubic and Power fits were developed with the training data set, which have been presented in Equations 5.8 through 5.11 respectively.

$P_c = 558.452 + 300.885\ W_P$ ……………………………………………………………………….........……(5.8)

$P_c = 8318.37 - 644.52x\ W_P + 28.74\ W_P{}^2$……...…………………………..………...………...….……(5.9)

$P_c = 34763.3 - 5499.07\ W_P + 325.126\ W_P{}^2 - 6.02\ W_P{}^3$…………………………….……..…..……..(5.10)

$P_c = 441.53\ W_P{}^{0.90}$…………………………………………………………………..……………..…..(5.11)

Where

P_C: Power Consumption (1000 kWh)

W_P: Water production volume (10^6 m^3)

Figure 5.17 shows the trend of each model with respect to the training data. Accordingly, it can be observed that all four models fit the data well when the range of water production volume is between 15 x 10^6 and 18 x 10^6 m^3. However, when the water production volume exceeds or precedes this range, it appears that the linear model might work best.

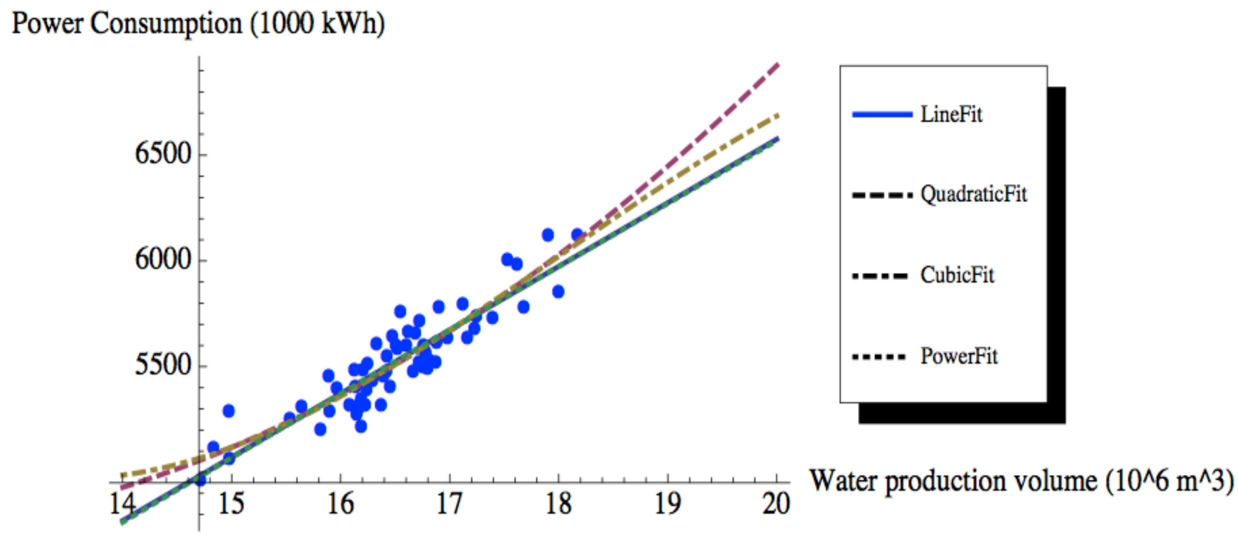


Figure 5.17: Fitted trends for Water production volume – Power consumption models

Table 5.11 presents the statistical results of the four Water production volume – Power consumption models, for both the training and testing sets. For the training set, the best results are obtained with the quadratic model (1.35% AARE and 81.79 x 10^3 kWh). The same model also provides the least AARE (1.61%) for the testing data. The errors in the testing data set does not vary significantly across different models, with the linear model and power model providing similar results. Hence for simplicity, the linear model has been chosen as the best-fit model.

Power consumption = 558.452 + 300.885 Water production volume

Table 5.11: Results for Water production volume – Power consumption model

Model 3: Water production volume – Power consumption relationship								
Input: Water production volume (10^6 m^3)								
Output: Power consumption (1000 kWh)								
Training								
Model	Exemplars	AARE	RMSE	Threshold static (%)				
		(%)	(1000 kWh)	0.5 %	1%	2%	5%	10%
Linear	40	1.48	95.27	20	30	70	100	100
Quadratic	40	1.35	81.79	22.50	27.50	75	100	100
Cubic	40	1.47	93.42	17.50	25	77.50	100	100
Power	40	1.36	82.26	20	30	67.50	100	100
Testing								
Model	Exemplars	AARE	RMSE	Threshold static (%)				
		(%)	(1000 kWh)	0.5 %	1%	2%	5%	10%
Linear	20	1.69	110.92	5	35	65	100	100
Quadratic	20	1.61	106.90	10	35	65	100	100
Cubic	20	1.61	106.59	10	35	65	100	100
Power	20	1.70	111.29	5	35	65	100	100

Figure 5.18 depict the observed and modeled data for the training set while Figure 5.19 shows the same for the testing sets, with the linear model for both cases. Accordingly, a very good fit can be seen for both the cases, for most part of the time series. The observed and modeled data appear to deviate slightly only towards the end of the time series. However, there is a good fit generally, suggesting the suitability of the linear model for this application.

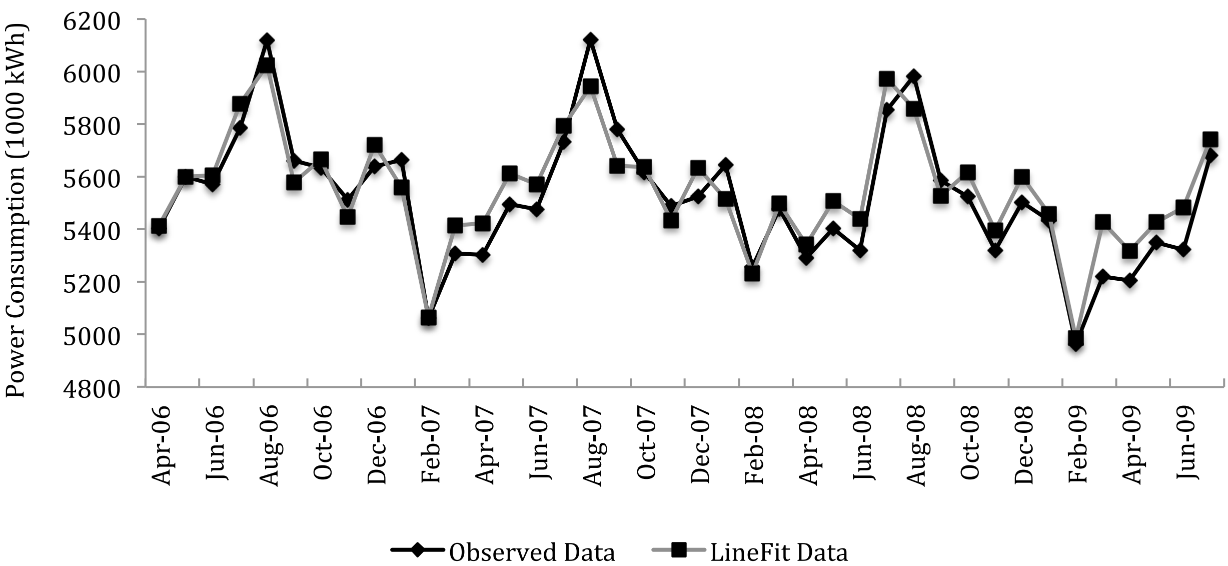


Figure 5.18: Observed and modeled data of Power consumption in training set using linear model

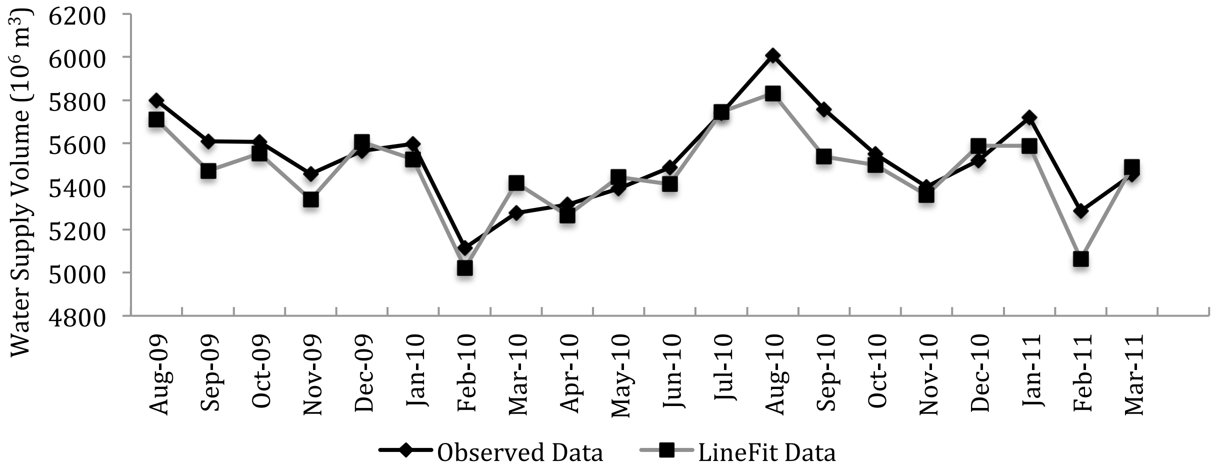


Figure 5.19: Observed and modeled data of Power consumption in testing set using linear model

5.5.7.2 Estimation of Per capita demand under different settings

Water production volume of Kobe City Waterworks in 2010 = 196.5 x 10^6 m^3

Losses = 4.8 %

Effective water supply volume = 187.068 x 10^6 m^3

Service population in 2010 = 1.532 Million

Per capita consumption = 334.54 L/cap/day

From the above calculations it is observed that the current per capita consumption of the customers of Kobe City Waterworks is 334.54 L/cap/day. This value is a little higher than the national average of 314 L/cap/day in 2008 (MLITT, 2008). In Japan, the per capita demand increased with economic growth in the 1990s but has been generally decreasing in the last few years. With advanced water saving technology in household appliances like dishwashers, washing machines and toilets, the consumption of water has been reducing. As seen in Figure 5.20, the per capita water consumption of the customers of Kobe City Waterworks has reduced from around 388 L/cap/day in 1996 to 334.54 L/cap/day in 2010.

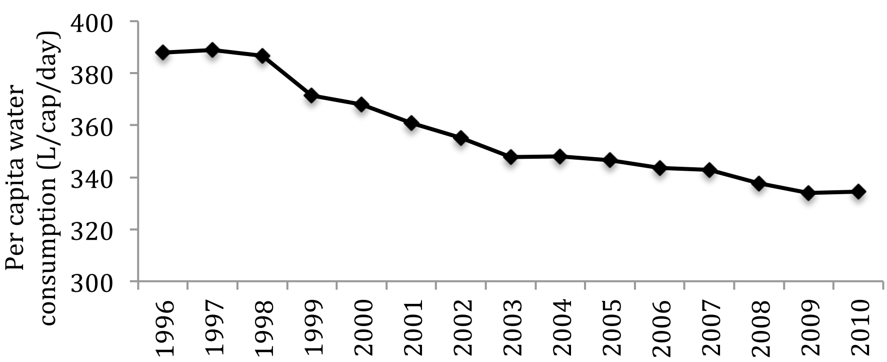


Figure 5.20: Per capita water consumption trend for Kobe City Waterworks

Because of the absence of per capita consumption forecasts for Kobe City in literature, an indirect method was used to estimate the per capita demand for Kobe by comparing the consumption trends of two other similar cities in Japan – Tokyo and Osaka. For Tokyo, the per capita water consumption has been projected to decrease to 217.7 L/cap/day in 2025 from 247.9 L/cap/day in 1996 (Nakagawa et al., 2010), amounting to a 12.2% decrease or 0.42% annual linear decrease.

For Osaka, the per capita water consumption has been projected to decrease to 249.8 L/cap/day in 2020 from 274.2 L/cap/day in 1996 (Nakagawa et al., 2010), amounting to 8.9% decrease or 0.36% annual linear decrease. There is very little difference between the annual linear decrease in per capita consumption for the two cities. Hence, it can be expected that the per capita consumption in Kobe City Waterworks will also reduce by a similar rate.

Because Kobe is geographically closer to Osaka, with similar climatic conditions, the annual linear rate of decrease in per capita consumption for Osaka (0.36%/year) has been used to estimate the per capita consumption of Kobe City.

5.5.7.3 Setting 1 (Year 2015)

Based on the data published by UN Habitat (2009), the population of Kobe is likely to be 1.539 Million in 2015.

Hence Projected population = 1.539 Million

Projected per capita water consumption = 334.54 - (0.36 x 5)% of 334.54 = 328.52 L/cap/day

Minimum water supply volume = 184.541 x 10^6 m^3

Minimum water production volume (4.8% losses) = 193.398 x 10^6 m^3

From equation 5.8,

Power Consumption = 558.452 + 300.885 Water production volume

Thus, Minimum annual power production = 58.750 x 10^6 kWh

Based on this setting, and the analysis performed earlier in Section 5.5.2 for power consumption under different scenarios of climate change, as presented in earlier in Figure 5.6 and Table 5.5, some interesting information is brought to the fore. This is presented in Figure 5.21, which shows the annual target power consumption for Kobe City Waterworks under different scenarios of climate change (increase in raw water turbidity) in order to meet the GHG emission targets.

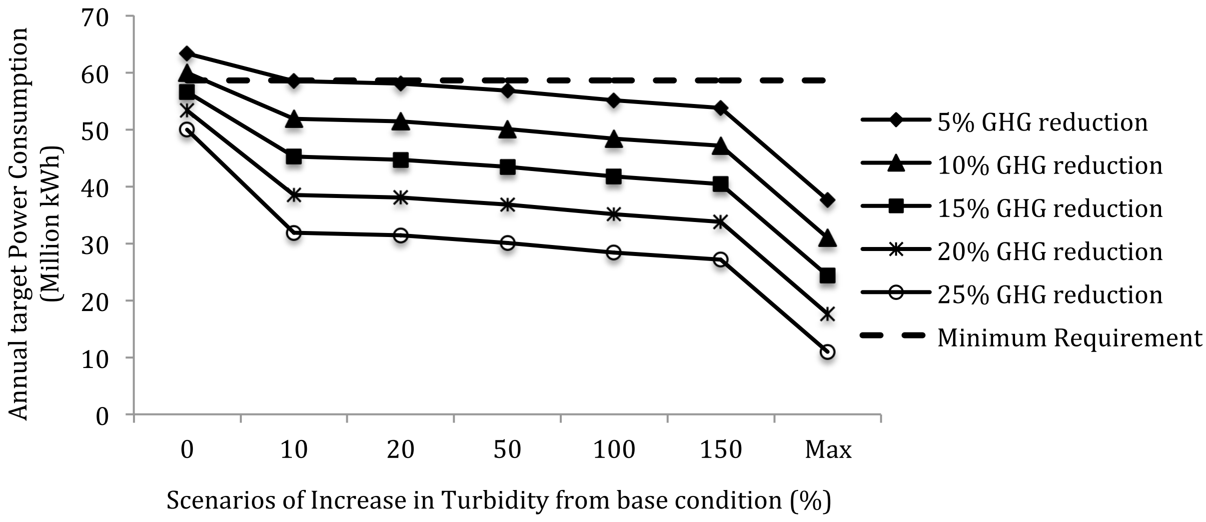


Figure 5.21: Annual target power consumption for 2015, under different scenarios of GHG reduction and increase in Turbidity

Accordingly, it can be seen that when there is no increase in turbidity (0 % increase or base condition), only up to 10% of GHG reduction is possible by merely reducing the production volume. The supply volume, in these cases of reduction, will not go below the minimum water production volume, thereby satisfying the criteria for minimum power consumption (and minimum per capita demand). GHG reduction above 10% for base condition is not possible unless some alternative form of energy is used. If the turbidity increases by 10% from the base condition, only 5% GHG reduction is possible with the existing sources of energy.

The situation becomes even graver when considering further increase in turbidity from base condition. Accordingly, it is seen that when the increase in turbidity is above 20% from base condition, even 5% reduction in GHG emissions is not possible. This clearly suggests that with the existing source of energy, it is difficult to target greater reduction in GHG emissions as well as meet the consumer demand. In order to meet the demand, and achieve higher GHG reduction targets, the utility will have to invest in renewable energy, or improve the energy efficiency of the existing supply system.

Table 5.12 presents the amount of renewable energy required for Kobe City Waterworks to meet the targets of GHG reduction, where it is seen that no renewable energy is required for GHG reductions up to 10% from base condition, under up to 10% increase in turbidity from base condition. Beyond these levels, renewable energy is required for all scenarios in increasing order of magnitude as the scenarios become more stringent.

Table 5.12: Additional annual Power (Million kWh) required in the form of renewable energy to meet GHG targets in 2015

GHG Reduction (%)	Increase in Turbidity (%)						
	0	10	20	50	100	150	Max
5	0	0.23	0.73	2.00	3.67	4.97	21.13
10	0	6.89	7.39	8.66	10.33	11.64	27.79
15	2.12	13.55	14.05	15.32	16.99	18.30	34.45
20	5.45	20.21	20.72	21.98	23.66	24.96	41.12
25	8.78	26.88	27.38	28.65	30.32	31.62	47.78

5.5.7.4 Setting 2 (Year 2020)

Based on data published by UN Habitat (2009), the population of Kobe in 2020 is likely to rise to 1.543 Million in 2020

Hence Projected population = 1.543 Million

Projected per capita water consumption = 334.54 - (0.36 x 10)% of 334.54 = 322.50 L/cap/day

Minimum water supply = 181.630 x 10^6 m^3

Minimum water production (4.8% losses) = 190.348 x 10^6 m^3

From equation 5.8,

Power Consumption = 558.452 + 300.885 Water production volume

Minimum annual power production = 57.831 x 10^6 kWh

When compared to setting 1, it is seen that the annual minimum power production required for setting 2 has decreased from 58.750 x 10^6 kWh to 57.831 x 10^6 kWh, a net decrease of 0.92 x 10^6 kWh. The change is quite small because the rate of population increase between the two settings is also small, 0.26 %, as the population is projected to rise from 1.539 Million to 1.543 Million. Hence, there is a very small difference between the two settings.

Figure 5.22 depicts the annual target power consumption under different scenarios of climate change (increase in raw water turbidity) in order to meet the GHG emission targets. The trend for this setting appears very similar to the first setting where only 5 and 10% reduction in GHG emissions is possible by reducing water production, under the base condition of raw water turbidity. In this setting, 5% reduction in GHG emissions is also possible under 10 and 15% increase in raw water turbidity from base condition. However for all other conditions, no reduction in GHG emissions is possible if only the current source of energy is used. As with the previous setting, additional energy in the form of renewable energy is required to cater to the demand.

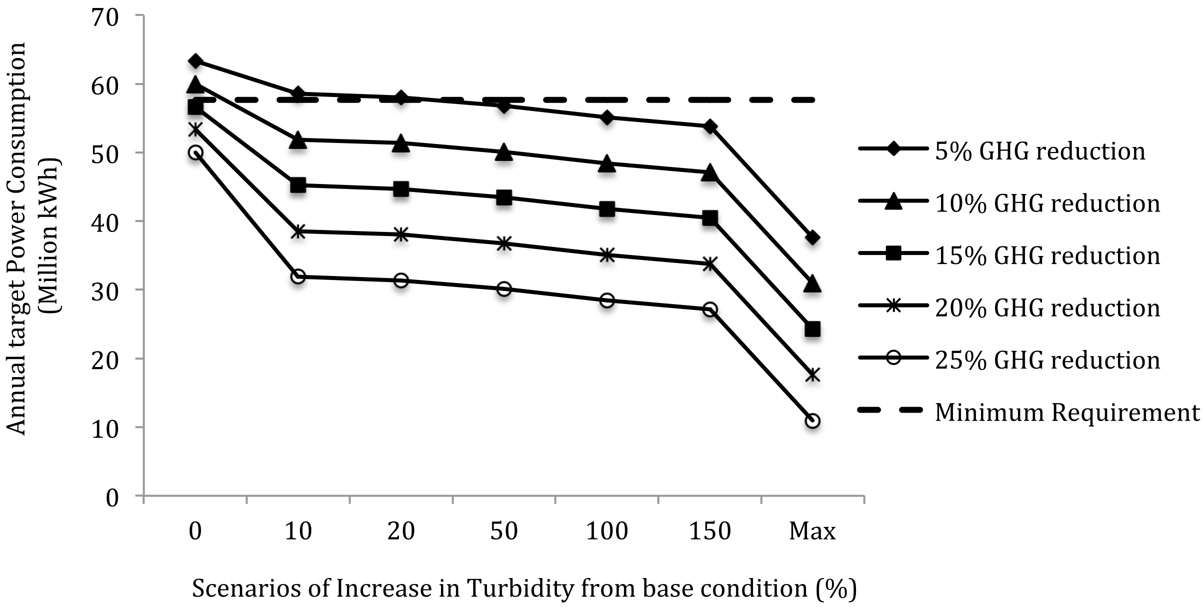


Figure 5.22: Annual target power consumption for 2020, under different scenarios of GHG reduction and increase in Turbidity

Table 5.13 presents the amount of renewable energy required to meet the GHG emission targets in 2020, which can be used by the Kobe City Waterworks to plan their activities. The trend of the values for different conditions of climate change in this setting is quite similar as that for the first setting. However the magnitudes in this table are slightly lower than the previous case because of the marginal decrease in minimum water production volume.

Table 5.13: Additional annual Power (Million kWh) required in the form of renewable energy to meet GHG targets in 2020

GHG Reduction (%)	Increase in Turbidity (%)						
	0	10	20	50	100	150	Max
5	0	0	0	1.08	2.75	4.06	20.21
10	0	5.97	6.47	7.74	9.41	10.72	26.87
15	1.20	12.63	13.13	14.40	16.07	17.38	33.53
20	4.53	19.29	19.80	21.06	22.74	24.04	40.20
25	7.86	25.96	26.46	27.73	29.40	30.71	46.86

5.5.7.5 Setting 3 (Year 2025)

Based on data published by UN Habitat (2009), the population of Kobe in 2020 is likely to stay constant at 1.543 Million in 2025.

Hence Projected population = 1.543 Million

Projected per capita water consumption = 334.54 - (0.36 x 15)% of 334.54 = 316.47 L/cap/day

Minimum water supply = 178.234 x 10^6 m^3
Minimum water production (4.8% losses) = 186.789 x 10^6 m^3

From equation 5.8,
Power Consumption = 558.452 + 300.885 Water production volume

Minimum annual power production = 56.76 x 10^6 kWh

The minimum power consumption in this setting reduces by 1.071 x 10^6 kWh, when compared to the previous setting. This is primarily because of the decrease in the projected per capita water consumption, which results in a lower water production volume. Figure 5.23 shows the annual target power consumption under the different scenarios of climate change.

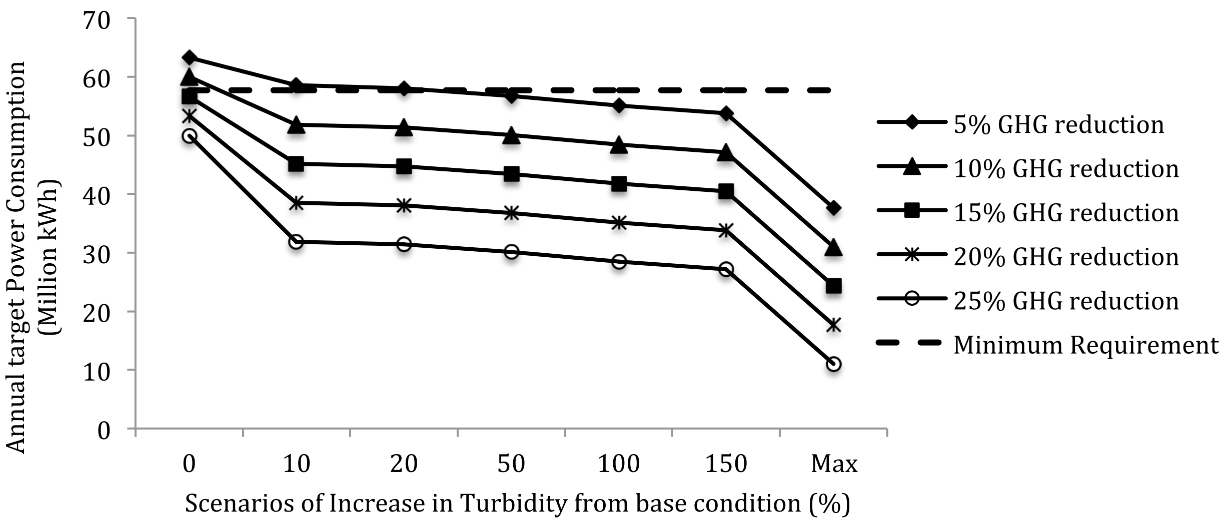


Figure 5.23: Annual target power consumption for 2025, under different scenarios of GHG reduction and increase in Turbidity

The results for this setting are a little different from the previous two settings. Here, it is seen that under the current condition of raw water turbidity, it is possible to reduce up to 15% GHG emissions from the base condition. Additionally, a 5% reduction in GHG emissions is possible under up to 50% increase in raw water turbidity. For all other scenarios of climate change, it is not possible to reduce the GHG emissions, necessitating the input of renewable energy to meet the demand.

Table 5.14 presents the magnitude of renewable energy required under the various conditions of change, where it is seen that no renewable energy is required for 5% reduction in GHG emissions under up to 50% increase in raw water turbidity. The magnitudes in this table are less than in Table 5.13, because of the reduced projected per capita consumption, as indicated earlier.

Table 5.14: Additional annual Power (Million kWh) required in the form of renewable energy to meet GHG targets in 2025

GHG Reduction (%)	Increase in Turbidity (%)						
	0	10	20	50	100	150	Max
5	0	0	0	0.01	1.68	2.98	19.14
10	0	4.90	5.40	6.67	8.34	9.65	25.80
15	0.13	11.56	12.06	13.33	15.00	16.31	32.46
20	3.46	18.22	18.73	19.99	21.67	22.97	39.13
25	6.79	24.89	25.39	26.66	28.33	29.63	45.79

5.5.7.6 Sensitivity of population estimates

The three settings developed in the previous sections were based on minimum per capita water consumption, which is a function of projected population. The projected population data of Kobe City used for this study was based on reports published by UN Habitat (2009). It is difficult to find population projection data only for Kobe City elsewhere. The Statistics Bureau, which keeps a record of past and projected population, has no specific projected data for Kobe City because all data is either at national level or prefectural level. Further, even work by independent researchers (e.g. Nishioka et al., 2011) is usually done at a prefectural level with different age groups, instead of city level.

There is a general consensus among researchers that the population in Japan is likely to decrease over time (Nishioka et al., 2011; Kaneko et al., 2008; Takahashi 2004), across all age groups except the elderly (above 65). The same view is reinforced by data projections made by the Statistics Bureau (2011). However, it is important to note that all these studies and projections are made on a national level, and not city level.

This study, however, based on data from UN Habitat, considers that there will be a marginal increase in the population of Kobe City from 2010 to 2020, after which it will be constant. Since this trend is opposite to that for the country as a whole, this section attempts to explore the sensitivity of population estimates on the final result.

According to the data used in the study,
Existing population for Kobe City in 2010 = 1.532 Million
Projected population for Kobe City in 2015 = 1.539 Million
Projected population for Kobe City in 2020 = 1.543 Million

The difference in population from 2010 to 2020 = 11,000 people only that accounts for a growth of only 0.7%, which is virtually negligible.

Further, assuming the per capita consumption of 334.54 L/capita/day (existing demand in 2010), the yearly water production for these extra 11,000 people will be only 1.34 x 10^6 m^3. This extra production is only 0.68% of the existing water production in 2010 (196.5 x 10^6 m^3).

In terms of power production, the annual power required to cater to 1.34 x 10^6 m^3, based on equation 5.8, is only 961.638 x 10^3 kWh, which is a mere 1.61% of the total annual power production in 2010 (59.62 Million kWh)

Hence, it can be seen that the growth rate of population for Kobe City used in this study is too small to make any significant impact on the final analysis. In other words, even if the population of Kobe were to remain constant from 2010 to 2025, or decrease at a constant rate from 2010 onwards, it will not make a significant difference to the results of this study. The Kobe City Waterworks, thus, can consider the scenarios generated in this study, seriously, without focusing on the accuracy of the population estimates.

5.5.7.7 Implications for tradeoff between water quality and reduction in GHG emissions

As seen in the three settings, by reducing the water production volume the GHG emissions can also be reduced. However, to account for minimum per capita demand, there is a limit up to which the water production volume can be reduced. Based on the three settings, it was seen that up to 15% reduction in GHG emissions is possible, for up to 50% increase in raw water turbidity. It may be recalled from the tradeoff analysis carried out earlier for Kobe City Waterworks that the optimal reduction in GHG emissions for the utility is between 10.5 and 14.5%. Hence, a major portion of the GHG reduction is possible by lowering the water production alone. However, before doing so, the affects of loss of revenue must be taken into account.

The consumer expectations of water quality can be better met by using advanced water treatments but this will require additional energy. This indicates that the P_{INT} will increase if more advanced treatment systems are used because 'water quality' is the main variable which influences the P_{INT}. This concept is shown in Figure 5.24, where two hypothetical situations are presented. The first condition is the 'Original Public Interest', which corresponds to the P_{INT} under the existing situation. As discussed earlier, when advanced treatment is used the P_{INT} will increase, which is represented by the 'Modified Public Interest' line in Figure 5.24. It can be seen that the optimal reduction in GHG emissions increases from OT_1 to OT_2, when advanced treatment is used. Hence, if additional energy can be available in the form of clean energy, the optimal reduction in GHG emissions will increase, leading to a greener water supply

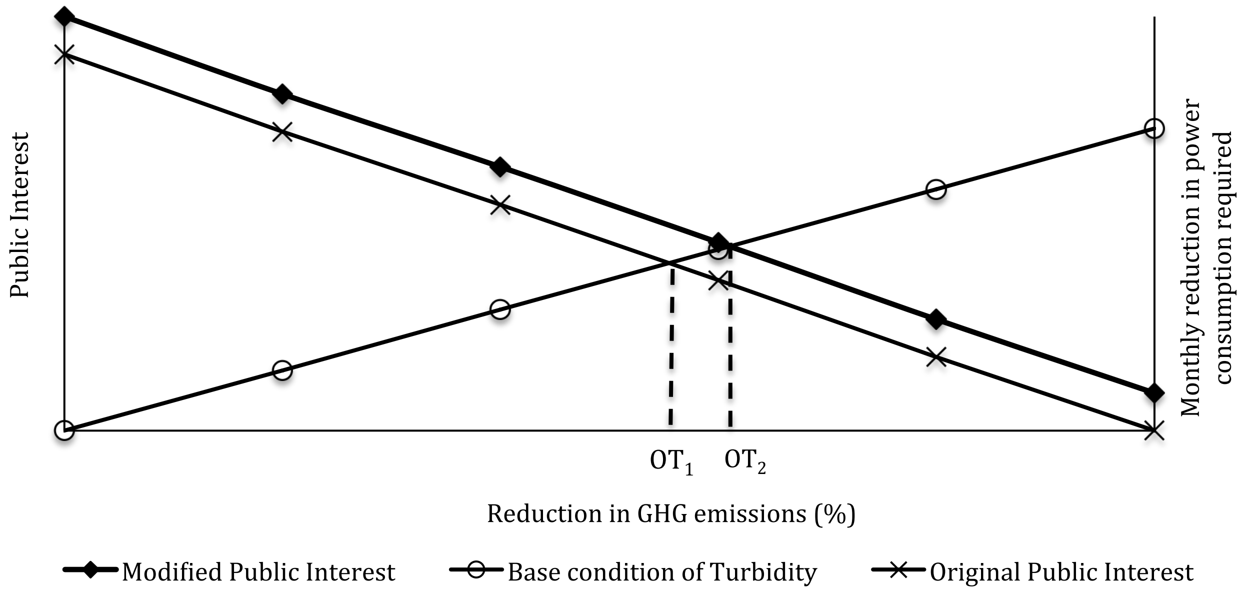


Figure 5.24: Effect of improved P_{INT} on optimal reduction in GHG emissions

5.6 Summary

This chapter focused on developing a methodology to design the tradeoff between meeting consumer expectations of water quality and reduction in energy use. 'Meeting consumer expectations' of water quality was represented by the P_{INT}, whereas reduction in energy use was represented by reduction in GHG emissions. The analysis was performed by evaluating the regression models developed in the earlier chapter, under different scenarios of climate change. All models were evaluated under two main scenarios of change: increase in raw water turbidity and reduction in GHG emissions. Considering 2010 as the base condition, the models were tested under 5, 10, 15, 20 and 25% reductions in GHG emissions from base condition, and 5, 10, 15, 20, 50, 100, 150% increases in raw water turbidity from base condition. The models were also evaluated for an extreme event case of 100 Degrees Turbidity (almost 3050% increase from base condition). Monte Carlo Simulations were used for the evaluation.

The tradeoff analysis suggested that the optimal reduction in GHG emissions was in the range 10.5 – 14.5% for the various scenarios of increase in raw water turbidity. As the raw water turbidity increases, the optimal value reduces. Further analysis was performed with three different water treatment systems – RSF + GAC, GAC + O_3, GAC + O_3 + UV. The range of optimal GHG reductions for the three treatment systems is between 10 and 15% from base condition. It was found that the optimal reduction in GHG emissions for RSF + GAC treatment is around 1.24 and 3 times the optimal reduction for GAC + O_3 and GAC + O_3 + UV treatments respectively.

To achieve reduction in GHG emissions, the utility will need to concentrate on three major thematic areas — reducing water production, improving efficiency of equipment, and increasing use of renewable energy. The study investigated practical settings for the Kobe City Waterworks for the years 2015, 2020 and 2025. After establishing a minimum per capita water demand, and following the population growth trend, the target power consumption was established for each year, under the various scenarios of change. The results suggest for all the three settings, only up to 15% reduction in GHG emissions, under up to 50% increase in raw water turbidity, is possible by only reducing the production volume. Any further reduction in production volume will result in per capita water consumption below the established minimum value, which may not be acceptable. However, reduced water production can very well lead to reduced revenues from water fees, so some financial analysis must be done before making a decision. To achieve higher GHG emission reduction targets (20 and 25%), while providing the minimum per capita demand, the Kobe City Waterworks will need to consider the usage of renewable energy (solar or wind). Further, the consumer expectations of water quality can be better met by using advanced water treatments but this will require additional energy. If this additional energy can be available in the form of clean energy, the optimal reduction in GHG emissions will increase, leading to a greener water supply. The study has provided the Waterworks with guidelines about the actual amount of renewable energy required under the various conditions of climate change.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Key findings of the study

The main objective of this study was to develop a methodology for water utilities in Japan to make tradeoffs between meeting customer expectations with respect to water quality and reducing energy use. Based on the study results, analysis, personal and professional perspectives, a number of key findings have emerged. These findings are described hereafter.

(a) Based on the development of the 9-cPIS, the key findings are

- The current Performance Indicator System recommended by the JWWA has not found widespread application, with very little participation from utilities, especially small utilities.
- The 9-cPIS developed in this study is a more condensed and manageable indicator system, which the utilities will find easier to manage.
- Apart from its use for self-evaluation, the 9-cPIS has remarkable applications in benchmarking, planning and management of water utilities through the PDCA cycle, and evaluating business models.

(b) Based on introducing "Public Interest P_{INT}" in supply systems, the key findings are

- The study respects the increasingly popular notion that stakeholder (public) participation in water management is imperative to ensure sustainability. However, until now there have been no studies on evaluating the public participation, and interest, in the water supply system.
- The concept of P_{INT} was developed to enhance the decision support system for the water utilities. Accordingly, five variables were found to form the factor, **P_{INT}: '**trust in water supplier', 'good quality tap water', 'Research and Development in utilities', 'equity of distribution' and 'price of water'.
- Alternately, the variables that formed the Public Disinterest factor (the opposite of Public Interest) were: 'employee productivity in utilities', 'financial state of utilities' and 'Research and Development in utilities'.
- Among the components of the 9-cPIS, only the Consumer Satisfaction for Water Quality shows a strong positive relationship with the P_{INT}, suggesting that good tap water quality is the most important PI from the consumers' point of view.

- A relationship has been found (derived) between the P_{INT} and the components of the 9-cPIS, via multiple regression modeling.
- The study strongly advocates that the P_{INT}, in water supply systems is site specific and will change from place from place. For example, while 'Research and Development in water utilities' may arouse Public Interest among Japanese consumers, this may not be the case in in developing countries.

(c) Based on developing tradeoff between meeting consumer expectations of water quality and energy reduction

- Presently, the only way for Kobe City Waterworks to reduce their GHG emissions is by reducing their power consumption because electricity is the only source of energy used by the utility.
- Because power consumption and water production volume have a very strong relationship, reduction in power consumption will naturally mean reduced water production.
- Climate change is likely to increase the raw water turbidity, and the study indicates that this increase causes the power consumption to increase.
- In an effort to reduce GHG emissions, meeting consumer expectations with respect to water quality is likely to suffer.
- A methodology for tradeoff between meeting consumers' expectation of water quality and reducing energy use has been developed for various scenarios of climate change. Accordingly, in the current situation the optimal reduction in GHG emissions from base condition for Kobe City Waterworks is 14.4%.
- For tradeoff analysis performed with various water treatment systems — RSF + GAC, GAC + O_3, GAC + O_3 + UV — it was found that the range of optimal GHG reductions for the three treatment systems is more or less similar, between 10 and 15% from base condition. However when compared relatively for 50% increase in raw water turbidity, the optimal reduction in GHG emissions for RSF + GAC treatment is around 1.24 and 3 times the optimal reduction for GAC + O_3 and GAC + O_3 + UV treatments respectively.
- The consumers' expectations of water quality can be better met by using advanced water treatments but this will require additional energy. If this additional energy can be available in the form of clean energy, the optimal reduction in GHG emissions will increase, leading to a greener water supply.
- Based on the results of practical settings developed for Kobe City Waterworks for the years 2015, 2020 and 2025, it was found that for all the three years, a maximum of 15% reduction in

GHG emissions, under up to 50% increase in raw water turbidity, is possible by only reducing the production volume. However, this can very well lead to reduced revenues from water fees, so some financial analysis must be done before making a decision.

- To achieve higher GHG emission reduction targets (20 and 25%), while providing the minimum per capita demand, the Kobe City Waterworks will need to consider the usage of renewable energy (solar or wind).

6.2 Recommendations

The overall objective of this study was to develop a tradeoff between meeting the consumers' expectation of water quality and reducing energy use. A number of interesting and pertinent results were obtained, both from a theoretical and practical point of view. The following recommendations are made based on the results of the study.

- The study recommends the usage of the 9-cPIS as a basic Performance Indicator mechanism for water utilities in Japan because of its simple structure and ease of evaluation. This does not in any way indicate that the PIs recommended by the JWWA are meaningless. If utilities desire to have a more stringent evaluation of their supply systems, they are free to adopt the original PIs. It is also recommended that a benchmarking exercise should be performed with the 9-cPIS not just across utilities but also within the utility – comparing the performance of the utility over time. Further, it is recommended that the utilities should use the 9-cPIS in planning and management, especially in the PDCA cycle.

- The general methodology developed in this study, to design the tradeoff between meeting consumer expectations of water quality and reduction in energy use, is recommended for use by all utilities in Japan. By improving on the methodology as described in the next section, and using their own data, utilities can design tradeoffs, and target an optimal reduction in GHG emissions.

- It is recommended that the Kobe City Waterworks should use this report as a reference in planning their GHG emission reduction targets. The tradeoff analysis performed in this study will help the utility to target an optimal reduction in GHG emissions, to ensure the right balance between meeting consumer expectations for water quality and reducing energy use. Because the per capita demand has been naturally declining over the last few years, they will be able to achieve some reductions in GHG emissions naturally. To maintain emission targets under more serious cases of climate change, especially increase in raw water turbidity, it is recommended that the utility should start planning and considering alternate energy sources like solar energy.

- It is also recommended that the utilities take efforts in spreading knowledge about climate change, and its impacts on water supply, among their consumers. This is to ensure that P_{INT} in water supply will increase, which will create a good support base for the utility. Such public support is crucial in implementing any adaptation measure that the utility deems feasible.

6.3 Scope for further research

All the efforts made in this study have culminated into developing a methodology to design a tradeoff between meeting consumer expectation of water quality and reduction in energy use. Due to time and data constraints there are a few limitations in the study, which can be improved by future research.

The tradeoff analysis performed in this study is based on the assumption that both meeting consumer expectations of water quality and reducing energy use are equally important and are given equal weightage. Further studies can consider converting the values of the two members of the tradeoff into a common unit and then perform the tradeoff.

This study only considered two main variables as the drivers of change of climate change: reduction in GHG emissions and increase in raw water turbidity. Future research can consider other relevant variables like increase in volume of precipitation, land use change etc.

This study is based on univariate analysis: only one variable was used to obtain the output of each model. To improve on model accuracy and to take into account additional explanatory variables, future research can consider multivariate analysis.

Due to data constraints, only three components of the 9-cPIS could be evaluated under the different scenarios of climate change. A thorough evaluation of all the nine components will provide a better framework for developing the tradeoff between meeting the consumers' expectation of water quality and reducing energy use.

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APPENDIX A

List of Performance Indicators recommended by the JWWA

IND CODE	INDICATOR	UNIT	DESCRIPTION
1. SUPPLY OF SAFE AND GOOD TASTING WATER			
(a) Conservation of water resources			
1001	Water Utilization	%	(Avg daily water supplied / Avg. daily water received from sources) x 100
1002	Water Rate margin (Drought index)	%	((Amount of water required to ensure no droughts/Max daily volume of distribution)-1) x 100
1003	Utilization rate of raw water	%	(Annual water supplied/ Annual intake) x 100
1004	Water retention rate	%	(Self-owned water/Total volume of water) x 100
(b) Water Quality Management			
1101	Degree of raw water quality monitoring	Number	Number of monitoring units
1102	Density of water quality inspection points	Points /100 km^2	(Water testing locations/Service area)
1103	Continuous automatic water quality monitoring	Units /1000m^3/day	(Number of continuous monitoring units / Avg daily water of distribution) x 1000
1104	Water quality non conformance rate	%	(Number of standards tests not met/Total number of tests) x 100
1105	Achievement of water in terms of musty odor	%	((1-max Geosim conc /Standard for Geosim)+(1-max 2-MIB conc /Standard for 2-MIB))/2 x 100
1106	Achievement of water in terms of chlorinous odor	%	((1-(max residual chlorine conc - permissible concentration)/permissible conc) x 100
1107	Trihelomethane concentration as ratio of permissible THM	%	(Maximum THM concentration/Permissible THM) X100)
1108	TOC concentration as ratio of permissible TOC	%	(Maximum TOC concentration/Permissible TOC concentration) X100)
1109	Pesticide concentration	%	Σ(xi/Xi)/n x 100 xi = max conc of pesticides measured each year; Xi = allowable standard conc; n= number of pesticides measured
1110	Heavy metal concentration	%	Σ(xi/Xi)/n x 100 xi = max conc of heavy metals measured each year; Xi = allowable standard conc; n= number of heavy metals measured

1111	Density of minerals in water	%	Σ(xi/Xi)/6 x 100 xi = max conc of minerals measured each year; Xi = allowable standard conc
1112	Organic matter concentration	%	Σ(xi/Xi)/4 x 100 xi = max conc of organic matter measured each year; Xi = allowable standard conc
1113	Organochlorine chemical concentration	%	Σ(xi/Xi)/9 x 100 xi = max conc of organochlorine measured each year; Xi = allowable standard conc
1114	Concentration of by products of disinfectants	%	Σ(xi/Xi)/5 x 100 xi = max conc of disinfectant byproducts measured each year; Xi = allowable standard conc
1115	Households without receiving tank	%	(No of houses using water supply system/Total households) x 100
1116	Activated carbon injection rate	%	(Activated carbon injection days in a year/ Number of days in that year) x 100
1117	Lead water pipes indicator	%	(Number of lead pipes/ Total number of pipes) x 100
	2. STABILITY OF WATER SUPPLY		
(a) Reliability of Water Supply			
2001	Drinking water storage per capita in event of disaster	L/person	((1/2(Total water supply) + Cap of emergency storage tanks)/Population served) x 100
2002	Per capita water distribution	L/d/person	(Average daily water distribution/Population served) x 1000
2003	Water reserve ratio	%	((Total cap of treatment plant - Daily water prod)/Total treatment plant cap)) x 100
2004	Capacity of distribution reservoirs	Days	(Total capacity of pond water distribution/Average daily distribution)
2005	Non service days	Days	Self explanatory
2006	Penetration rate	%	(Population served/Total population in service area) x 100
2007	Pipe Density	km/km^2	(Length of distribution pipes/Total service area)
2008	Water meter density	Number/km	Number of water meters/length of pipes)
2101	Rate of aging water treatment plants	%	(Capacity of treatment plants exceeding design life/Total capacity) x 100
2102	Aging equipment rate	%	(Number of aged equipment and machinery/Total number of equip and machinery) x 100
2103	Aging pipeline rate	%	(Length of aged pipes/Total length of pipes) x 100
2104	Pipeline renewal rate	%	(Renewed length of pipeline/Total length of pipes) x 100
2105	Pipeline rehabilitation rate	%	(Repaired length of pipeline/Total length of pipes) x 100
2106	Valve replacement rate	%	(Num of replaced valves/Total number of valves) x 100

2107	Pipeline extension rate	%	(Length of extended new pipeline/Total pipeline length) x 100
(b) Risk Management			
2201	Water quality accident rate	Number	Number of cases in a year
2202	Accident rate of trunk (main) pipelines	Cases/100km	(Number of cases/100 km length of trunk pipeline)
2203	Rate of distribution when accidents occur	%	(Volume of water distributed up to 24hrs after accident/Average daily volume distributed) x 100
2204	Rate of service provision when accidents occur	%	(Population served up to 24hrs after accident/Total population of service area) x 100
2205	Water based density for emergency	Point/100km^2	(Total number of ponds supplying emergency water/Total service area)
2206	Water purification rate	%	(Raw water capacity / Treated water capacity) x 100
2207	Water facilities seismic rate	%	(Anti seismic design capacity of treatment plants/Total treatment capacity) x 100
2208	Pump station seismic facility rate	%	(Anti-seismic design capacity of pump stations/Total pump capacity) x 100
2209	Distribution reservoir seismic facility rate	%	(Anti-seismic design capacity of reservoirs/Total reservoir capacity) x 100
2210	Rate of seismic pipes	%	(Pipelines designed for seismic loading/Total length of pipes) x 100
2213	Water vehicles ratio	Vehicles/ 1000 per	(Number of water vehicles/Population served) x 1000
2214	Potable plastic tanks/plastic packs	Num/ 1000 per	(Number of potable plastic tanks/packs per 1000 persons)
2215	Emergency water tank capacity	m^3/1000 per	(Capacity of emergency water tanks / Population served) x 1000
2216	Emergency power generation capacity	%	(Emergency power generation capacity / Total power generation capacity) x 100
2217	Alarm rate	%	(Number of facilities with alarms/Total number of facilities) x 100
2218	Incidents of freezing of plumbing fixtures	Cases/1000 cases	(Annual number of frozen plumbing fixtures/Total service connections) x 1000

3. SUSTAINABILITY OF WATER SUPPLY			
(a) Operational Infrastructure Characteristics			
3001	Operating balance ratio	%	(Operating revenue/Operating costs) x 100
3002	Current account balance ratio	%	(Operating profit /Operating costs) x 100
3003	Total balance ratio	%	(Total revenue/Total cost) x 100
3004	Cumulative net loss ratio	%	
3005	Carryover ratio (expenditure and revenue)	%	(Carryover capital/Total revenue) x 100
3006	Carryover ratio (capital income)	%	(Carryover capital/Total capital) x 100
3007	Water revenue per employee	1000 Yen/person	(Water revenue/Number of employees)
3008	Staff salary as ratio of total revenue	%	(Amount of staff salary/Total revenue) x 100
3009	Corporate bond interest rate of return for water supply	%	(Interest on corporate bonds/Total revenue) x 100
3010	Depreciation as ratio of revenue	%	(Depreciation/Total revenue) x 100
3011	Redemption rate of revenue bonds	%	(Corporate bond redemption proceeds/Water revenue) x 100
3012	Percentage of outstanding revenue bonds	%	(Balance of corporate bonds/Water revenue) x 100
3013	Supply to Production cost ratio of water	%	(Price of water/Cost of water) x 100
3014	Water supply revenue	Yen/m^3	(Revenue earned from water supply/Amount of water supplied)
3015	Water production cost	Yen/m^3	(Total cost of producing water/Amount of water supplied)
3016	Price for households using up to 10m3 water	Yen	Water price for households using up to 10m3 of water/month
3017	Price for households using up to 20m3 water	Yen	Water price for households using up to 10m3 of water/month
3018	Yield of water		
3019	Facility utilization rate	%	(Average daily water supplied/Water supply capacity of the facility) x 100
3020	Maximum facility utilization rate	%	(Maximum daily water supplied/Water supply capacity of the facility) x 100
3021	Load factor	%	(Average daily water supply/Max daily water supply) x 100

3022	Assets to Debts ratio	%	(Current assets/Current liabilities) x 100
3023	Percentage of equity	%	((Equity + retained earnings)/(Total liabilities)) x 100
3024	Fixed assets Ratio	%	(Assets/(Capital+Profit)) x 100
3025	Depreciation rate corporate bonds vs. principal repayment	%	(Corporate bond principal repayment/Depreciation current year) x 100
3026	Fixed assets turnover	Time	((Operating revenue-revenue const contract)/(Fixed assets at beginning + Fixed assets at end)/2)
3027	Utilization rate of fixed assets	m^3/10,000 Yen	(Total water supply/Tangible assets) x 10000
(b) Capacity building and technology			
3101	Qualified personnel indicator	Person/ per	(Number of JWWA qualified employees/Total employees)
3102	Degree of qualified civilians	Cases/per	
3103	External training rate	Hours	(Number of externally trained staff x Number of hours trained)/Total employees
3104	Internal training rate	Hours	(Number of internally trained staff x Number of hours trained)/Total employees
3105	Technical staff ratio	%	(Number of technical staff/Total employees) x 100
3106	Average work experience ratio	Years/per	(Total work experience of all staff/Number of staff)
3107	Development staff ratio	%	(Number of staff involved in technological development/Total number of staff) x 100
3108	Development expense ratio	%	(Cost spend in tech development/Total revenue) x 100
3109	Amount of water supplied per unit staff	m^3/ per	(Amount of water supplied/Total employees)
3110	Meters per unit staff	Number/per	(Total number of meters/Total employees)
3111	Health affairs	%	(Total absence days due to health reasons/Total staff duty days) x 1000
3112	Tap water consumption rate	%	(Number of respondents using tap water for drinking/Total number of respondents)
(c) Enhancement of Quality of service to consumers			
3201	Information disseminated to consumers	Number	(Magazines/information letters distributed/Number of household connections)
3202	Rate monitor	Number/1000 per	(Number of people contacted for survey requested/Population served) x 1000
3203	Consumers involved in surveys	Number/1000 per	(Number of survey respondents/Population served) x 1000
3204	Visitors rate to treatment plant	Num/1000per	(Number of visitors/Service population) x 1000
3205	Percentage of complaints about	Cases/1000	(Water service complaints/Total number of respondents)

	water services	per	x 1000
3206	Percentage of water quality complaints	Cases/1000 per	(Water quality complaints/Total number of respondents) x 1000
3207	Percentage of water rate (pressure) complaints	Cases/1000 per	(Water rate complaints/Total number of respondents) x 1000
3208	Audit Requests	Cases	(Number of requests made for audits in a year)
3209	Information disclosure	Cases	(Number of requests made for information about services)
3210	Per capita number of reception staff	Number	Number of reception staff/Service Population

4. ENVIRONMENTAL CONSIDERATIONS			
(a) Reducing global warming and increasing awareness about environment protection			
4001	Power consumption	kWH/m^3	(Total power consumption /Annual distribution of water)
4002	Energy consumption	MJ/m^3	(Total energy consumption in all facilities/Annual distribution of water)
4003	Renewable energy utilization rate	%	(Power used from renewable energy like wind, sun etc/Total power use) x 100
4004	Rate of recycle and reuse	%	(Recycled solid waste/Total solid waste generated) x 100
4005	Construction by product recycling rate	%	(Amount of recycled construction by products/Total amount of const by products) x 100
4006	Greenhouse gases emissions	$gCO2/m^3$	(Amount of carbon dioxide emitted/ Total water produced)
(b) Sound water cycle			
4101	Groundwater use index	%	(Volume of groundwater pumped/Total water use)

5. BUSINESS MANAGEMENT OF WATER SUPPLY SYSTEMS			
(a) Operation management			
5001	Proper supply pressure rate	%	((No of days when pressure was measured in the proper range/(total pressure measurement points x number of days in the years) x 100
5002	Implementation rate for cleaning pond water	%	((Capacity of dist reservoirs cleaned in 5 years)/5/Total capacity) x 100
5003	Average pumping performance	%	(Op. time of all pumps/(Total number of pumps x Number of days in a year x 24)) x 100
5004	Metering error rate	Cases/1000 cases	(Number of erroneous meters/Total number of meters) x 100
5005	Billing error rate	Cases/1000 cases	(Number of billing errors/Total number of billings) x 100

5006	Non-payment index	%	(Total fee not paid at the end of the year/Total fee amount) x 100
5007	Rate of stoppage of service	Cases/1000 cases	(Number of stops/Number of service connections) x1000
5008	Contract meter commissioned rate	%	(Number of contracted water meters/Total water meters) x 100
5009	Third party contract rate	%	(Capacity of treatment plants commissioned to 3rd party/Total capacity) x 100
(b) Maintenance			
5101	Water treatment plant accident rate	Cases in 10 years/	(No of accidents in 10 years causing stoppage /Total number of treatment plants)
5102	Ductile iron pipe ratio	%	(Total ductile iron pipe length/Total pipe length) x 100
5103	Pipeline accident rate	Cases/100 km	(Number of pipeline accidents/Total pipe length) x 100
5104	Steel pipeline accident rate	Cases/100 km	(Number of steel pipeline accidents/Total length of steel pipes) x 100
5105	Non iron pipeline accident rate	Cases/100 km	(Number of accidents in non iron pipes/ Total length of non iron pipes) x 100
5106	Accident rate for water supply pipes	Cases/1000 cases	(No of accidents in pipes/Total service connections) x 1000
5107	Leakage rate	%	(Amount of leakage per year/Annual distribution) x 100
5108	Leakage volume per service connection	m^3/year/ connect	(Annual leakage volume/No of service connections)
5109	Turbidity outage time	Hours	(Shutdown when turbidity increases x Population affected)/Service population
5110	Equipment inspection rate	%	(Number of equipment inspected/ Total number of equipment) x 100
5111	Pipeline inspection rate	%	(Length of pipeline inspected/Total length of pipeline) x 100
5112	Valve density	Units/km	(Number of valves installed/Total pipe length)
5113	Hydrant inspection rate	%	(Number of hydrants inspected/Total number of hydrants) x 100
5114	Hydrant installation density	Units/km	(Number of hydrants installed/Total length of pipes)
5115	Cistern water supply teaching		

6. INTERNATIONAL RELATIONS			
6001	Degree of international cooperation	Man-week	(Number of co-agents abroad x length of stay)
6101	Number of international relations	Number	(Number of interactions with international agencies)

APPENDIX B

Questionnaire for Investigating Public Interest in water supply

Background information for responders

Water is the driver of life. Scientific opinion suggests that water resources are becoming more vulnerable to changes brought about by natural and human activities. Hence, the water supply utilities need to prepare to tackle the changes by planning adaptation strategies. An important part of the planning process is to consider the views, concerns and opinions of all stakeholders. Since consumers are the key focus of any water supply development plan, this questionnaire is an attempt to gauge the consumer's perspective with respect to what is important to them.

This study is being carried out by the Kyoto University as part of a research project to investigate feasible adaptation strategies for water supply utilities in Japan in context of future change. We would appreciate it if you could spare a few minutes and fill out this questionnaire. All information provided by you will be kept confidential and used for research purposes only.

SET A

Gender

❏ Female ❏ Male

Age

❏ 19 and below ❏ 20-29 ❏ 30-39

❏ 40-49 ❏ 50-59 ❏ 60 and above

SET B

Please indicate your interest and agreement with respect to the following aspects of a the water supply system by checking (✓) on the appropriate box

1. How important is good quality tap water to you?

❏ Very important ❏ Important ❏ Undecided

❏ Slightly important ❏ Not important

2. How important is the price of water to you?

❏ Very important ❏ Important ❏ Undecided

❏ Slightly important ❏ Not important

3. How important is customer service to you?

❏ Very important ❏ Important ❏ Undecided

❏ Slightly important ❏ Not important

4. How important is trust in your water supplier to you?

❏ Very important ❏ Important ❏ Undecided

❏ Slightly important ❏ Not important

5. How important is the state of research and development in your water utilities to you?
❑ Very important ❑ Important ❑ Undecided
❑ Slightly important ❑ Not important

6. How concerned are you about the financial condition (profit and loss) of your water supply utilities?
❑ Very concerned ❑ Concerned ❑ Undecided
❑ Slightly concerned ❑ Not concerned

7. How concerned are you about the productivity of employees (the amount of work that employees do) in your water supply utilities?
❑ Very concerned ❑ Concerned ❑ Undecided
❑ Slightly concerned ❑ Not concerned

8. How important is equity of distribution to you? (Water is supplied to everyone irrespective of personal wealth, social status etc.)
❑ Very important ❑ Important ❑ Undecided
❑ Slightly important ❑ Not important

Additional comments (Please use the space below for any additional comments that you may have)

日本における水道事業に対する消費者の意識調査

回答者への説明

水は生命の源です。科学的意見によると、自然と人類活動によって水資源が脆弱的に変化しました。このような変化に対応するため、水道施設の適用戦略を計画する必要があります。その計画過程の重要な部分は、全ての利害関係者の関心、意見、見解を考慮することです。任意の給水開発計画の主な焦点が消費者であるため、このアンケートを通じて、消費者の視点から「自分たちにとって何が重要であろうか」を評価することに試みしたいと思います。

本研究では、将来の変化を背景として、日本の給水施設に対して実現可能な適応戦略を検討する研究プロジェクトの一環として、京都大学で実施されています。お忙しい所、お手数ですが、このアンケートにご記入していただけたら幸いです。個人情報は、アンケート結果の分析以外の目的には使用いたしません。

セットA

性別

o 女性　o 男性

年齢

o 15-25　o 26-40　o 41-55

o 56-70　o Above 70

セットB

水供給システムへの関心について、次の選択肢に該当する四角［□］にチェックマークをつけて下さい。

1. あなたにとって、水質はどのぐらい重要だと思いますか。

o 非常に重要　o 重要　o 分からない

o やや重要　o 重要でない

2. あなたにとって、水道料金はどのぐらい重要だと思いますか。

o 非常に重要　o 重要　o 分からない

o やや重要　o 重要でない

3. あなたにとって、顧客サービスはどのぐらい重要だと思いますか。

o 非常に重要　o 重要　o 分からない

o やや重要　o 重要でない

4. あなたにとって、水道事業への信頼はどのぐらい重要だと思いますか。

o 非常に重要　o 重要　o 分からない

o やや重要　o 重要でない

5.なたにとって、水道事業の研究開発状態はどのぐらい重要だと思いますか
o 非常に重要 o 重要 o 分からない
o やや重要 o 重要でない

6. なたは給水施設の財務状況(損益)にどのぐらいの関心を持っていますか。
o 非常に関心がある o 関心がある o 分からない
o やや関心がある o 関心がない

7.あなたは給水施設に対する従業員の生産性(従業員が行う作業の量)にどのぐらいの関心を持っていますか。
o 非常に関心がある o 関心がある o 分からない
o やや関心がある o 関心がない

8.あなたにとって、配分の公平さはどのぐらい重要だと思いますか。(水の供給は個人的な富、社会的地位などに関わらず、全ての人に供給されている)
o 非常に重要 o 重要 o 分からない
o やや重要 o 重要でない

APPENDIX C

Data collected from Kobe Waterworks

C-1 Power consumption and Water production data

Year	Month	Power consumption (kWh)	Water production (m^3)	Year	Month	Power consumption (kWh)	Water production (m^3)
2006	April	5403764	16133820	2009	November	5458424	15889860
2006	May	5599583	16759790	2009	December	5563330	16778910
2006	June	5570876	16770410	2010	January	5598895	16505990
2006	July	5784825	17679000	2010	February	5115015	14833650
2006	August	6119989	18168870	2010	March	5277299	16144550
2006	September	5661130	16684630	2010	April	5314168	15639680
2006	October	5635430	16978990	2010	May	5389218	16236940
2006	November	5513530	16246580	2010	June	5487709	16126290
2006	December	5640606	17158760	2010	July	5740585	17242400
2007	January	5664540	16617960	2010	August	6006066	17527840
2007	February	5062602	14978400	2010	September	5758028	16545490
2007	March	5308721	16144140	2010	October	5550653	16424970
2007	April	5301991	16168190	2010	November	5398497	15962950
2007	May	5495201	16794830	2010	December	5520212	16718460
2007	June	5477051	16661640	2011	January	5718962	16722560
2007	July	5731177	17393340	2011	February	5286892	14972360
2007	August	6122262	17902230	2011	March	5455522	16390160
2007	September	5780339	16898630				
2007	October	5617191	16878990				
2007	November	5488833	16204180				
2007	December	5524144	16869560				
2008	January	5643329	16473940				
2008	February	5256096	15534560				
2008	March	5478530	16419400				
2008	April	5290592	15896570				
2008	May	5402903	16453440				
2008	June	5320902	16222540				
2008	July	5852755	17994800				
2008	August	5982955	17616150				
2008	September	5586274	16517410				
2008	October	5525953	16812940				
2008	November	5320383	16079760				
2008	December	5502116	16754950				
2009	January	5435752	16289020				
2009	February	4963922	14713230				
2009	March	5219376	16185150				
2009	April	5204415	15815310				
2009	May	5348216	16185650				
2009	June	5321455	16369250				
2009	July	5680763	17225290				
2009	August	5798733	17118340				
2009	September	5609059	16328690				
2009	October	5604967	16602410				

C-2 Water Quality Data

Year	Month	Raw Water Turbidity (Degrees)	Month	Raw Water Turbidity (Degrees)	Month
2006	May	2.1	2008	October	2.4
2006	July	24	2009	February	1.7
2006	October	2.3	2009	May	2.2
2007	February	2.2	2009	July	2.5
2007	May	2.0	2009	October	2.9
2007	July	1.9	2010	February	1.7
2007	October	3.1	2010	May	1.9
2008	February	3.5	2010	July	5.8
2008	May	1.2	2010	October	3.4
2008	July	1.5	2011	February	2.0

C-3 Other data

Variables	**Unit**	**2011**	**2010**	**2009**	**2008**	**2007**	**2006**
Service population	Number	1539349	1532764	1529323	1525867	1523531	1521229
Water production	1000 m^3	NA	196510	195798	197536	200200	200321
Operating revenue	Yen	32823296	32846755	33446346	34084637	33983477	33990305
Non-op revenue	Yen	2623592	2771031	2790489	2898168	3040392	3197791
Acquisition revenue	Yen	933659	1237197	1272723	1177633	1360721	1722847
Total revenue	Yen	36380547	36854983	37509558	38160438	38384590	38910943
Operating expense	Yen	25605411	26163066	26934637	27411450	27191331	27356201
Non-op expense	Yen	10440176	10376912	10201137	10310709	10756142	11114136
Acquisition expense	Yen	67086	53021	61709	61035	74741	65438
Total expense	Yen	36112673	36592999	37197483	37783194	38022214	38535775
Unit cost of water	Yen/m^3	NA	NA	189.32	188.38	187.73	190.19
Unit price of water	Yen/m^4	NA	NA	174.06	175.53	176.58	176.1
Price of water (up to 10 m^3)	Yen/m^5	92.4	92.4	92.4	92.4	92.4	92.4
Price of water (up to 20 m^3)	Yen/m^6	152.25	152.25	152.25	152.25	152.25	152.25

Variables	**Unit**	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**
Service population	Number	1515453	1511012	1505085	1498965	1490209	1515453
Water production	1000 m^3	201315	201594	200652	204133	206110	201315
Operating revenue	Yen	33473605	33863677	34941758	35573185	36193243	33473605
Non-op revenue	Yen	3373622	2842551	2956704	3167854	3028141	3373622
Acquisition revenue	Yen	2863837	3014197	2987910	3172432	3198268	2863837
Total revenue	Yen	39711064	39720425	40886372	41913471	42419652	39711064
Operating expense	Yen	27379170	27713898	28774929	30660857	30959035	27379170
Non-op expense	Yen	11975735	12316603	11637961	11895032	12425326	11975735
Acquisition expense	Yen	66887	61544	66898	53985	117826	66887
Total expense	Yen	39421792	40092045	40479788	42609874	43502187	39421792
Unit cost of water	Yen/m^3	194.64	198.03	203.65	210.82	212.87	194.64
Unit price of water	Yen/m^4	175.93	176.37	176.51	177.87	179.39	175.93
Price of water (up to 10 m^3)	Yen/m^5	92.4	92.4	88	88	88	92.4
Price of water (up to 20 m^3)	Yen/m^6	152.25	152.25	145	145	145	152.25

Variables	**Unit**	**1999**	**1998**	**1997**	**1996**	**1995**
Service population	Number	1469170	1419170	1412443	1410206	1480642
Water production	1000 m^3	209295	210386	210604	209775	204758
Operating revenue	Yen	37032492	36121581	35040653	28927000	21978000
Non-op revenue	Yen	2969216	3244334	3567112	5406270	3117379
Acquisition revenue	Yen	4126582	3843406	4912464	2540674	2010215
Total revenue	Yen	44128290	43209321	43520229	36873944	27105594
Operating expense	Yen	30699848	31233573	31674672	28227381	28453438

Non-op expense	Yen	11855014	10790737	10162834	10964736	11474687
Acquisition expense	Yen	129263	141811	268010	1469088	NA
Total expense	Yen	42684125	42166121	42105516	40661205	39928125
Unit cost of water	Yen/m^3	206.23	202.31	200.25	193.17	NA
Unit price of water	Yen/m^4	180.56	175.9	174.79	152.75	NA
Price of water (up to 10 m^3)	Yen/m^5	88	88	88	74	74
Price of water (up to 20 m^3)	Yen/m^6	145	145	145	120	120

NA: Not Available